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Soviet Strong-Motion and Vibration-and-Blast Seismographs

Charles Shishkevish

A Report prepared for

DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

Rand
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A description of the current state of the art of Soviet strong-motion and vibration-and-blast seismographs, taken from Soviet publications available in the United States through early 1975. It is intended primarily for U.S. seismologists working with strong-motion data, and persons interested in Soviet advances in seismic instruments, the report contains: (1) four tables listing the technical specifications of Soviet seismometers and accelerometers used most widely in galvanometrically recording strong-motion seismographs; (2) a description of recorders; characteristics of four of the most widely used strong-motion instruments; and specifications of direct-recording, three-component seismograph systems. Also treated are auxiliary equipment, including seismic triggers, and seismic engineering networks. An extensive bibliography is included. Refs. (BG)

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PREFACE

This Report presents data from open-source literature on Soviet strong-motion and vibration-and-blast seismographs, prepared as part of a continuing Rand study, sponsored by the Defense Advanced Research Projects Agency, of selected areas of Soviet science and technology. The Report contains most of the information on Soviet strong-motion and vibration-and-blast instruments available in the United States from Soviet publications through early 1975 and is intended primarily for U.S. seismologists working with strong-motion data and for those interested in Soviet advances in seismic instruments. It extends a two-part Rand Report by the same author, *Soviet Seismographic Stations and Instruments*, Part I, R-1204-ARPA, May 1974, and Part II, R-1647-ARPA, ~~forthcoming~~, which treat Soviet seismographic stations, the seismic instruments used at these stations, and recently developed seismic instruments and seismograph components.

SUMMARY AND CONCLUSIONS

Since the early 1950s the Soviet preference in the design of strong-motion instruments has been seismographs that consist of conventional, short-period ($T_s \leq 5$ sec), moving-coil (velocity), pendulum seismometers coupled with heavily overdamped ($D_g = 10$ to 30) galvanometers with natural frequencies $f_g \approx 5$ to 15 Hz.* Special efforts are made to design the galvanometers with a high ratio of critical damping resistance to coil resistance (R_{cr}/R_g) to obtain the desired heavy damping with reasonably large shunt damping resistance, and thus avoid excessive signal loss. The overall response of the resulting seismograph is then proportional to displacement and the magnification sensitivity curve is flat in the frequency range 0.5 to over 30 Hz.

Seismographs with similar components are often used in engineering seismology as velocity meters. This use is achieved by increasing the natural frequency of the galvanometer (often to 120 Hz) and at the same time reducing its R_{cr}/R_g ratio to obtain, again with reasonable coupling resistance, damping of 0.7 critical. The resulting system exhibits flat velocity sensitivity for frequencies between f_s and f_g.

Although not specifically mentioned by Soviet seismologists, a common problem with strong-motion instruments of this design is that the allowable physical range of motion of the seismometer inertial mass will often be exceeded during strong motion of the ground. The Soviet solution applicable to pendulum seismometers is to extend the center of oscillation (reduced length) far beyond the dimensions of the physical system, usually by increasing period through counterbalance weights on the pendulum. This reduces the pendulum motion without sacrificing the frequency response of the seismograph. However, it results in attenuation of the relative motion, and thus of the output signal, at the coil by the ratio $\ell_{coil}/\ell_{c.osc.}$. Even with this design feature, seismometers

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*In Soviet terminology, these are referred to as "overdamped, low-frequency galvanometers," or just "overdamped galvanometers"; galvanometers with $f_g \approx 30$ Hz and optimal damping 0.7 critical are called "high frequency galvanometers."

with reduced lengths as large as one meter (VBP-3) still cannot record earthquakes of intensity I > VIII (ground motion exceeding 5 mm). Also, large reduced pendulum length, with the center of mass very near the hinge, increases the sensitivity of vertical seismometers to rotation in the pendulum's plane of oscillation and of horizontal seismometers to tilts in the sensitive direction.

Strong-motion seismographs generally drive light-beam oscillographs operated in a standby mode. Among the most recent of these is the six-channel ISO-2M oscillograph, which records on 35-mm film at a speed of 5 or 10 mm/sec, and is capable of recording up to five events of 30- or 60-sec duration in up to six months of unattended operation. The unit is started by an electronic trigger connected to the signal coil of the seismometer, with the loss of motion less than 0.2 sec. Improved optics (trace thickness less than 0.2 mm) makes it possible to identify signals with frequencies up to 25 Hz.

Recent developments include the SSRZ accelerograph with direct optical recording on 35-mm film of the deflection of a 20- to 25-Hz pendulum with sensitivity of 12 to 50 mm/g. The unit is triggered by a 3-Hz vertical seismometer and, except for pendulum details, is in principle very similar to standard torsion units operating in the United States.

Another new strong-motion seismograph is the ESS-5 three-component system with direct optical recording. The use of low-frequency (0.3- to 1-Hz) pendulums, with damping adjustable between 0.3 and critical, results in flat magnification with a gain of between 1 and 30 at frequencies above 1 Hz. Up to one month of continuous operation is achieved by the unique design of the recording assembly which makes it possible to register traces along the width rather than the length of a stationary film that is rapidly advanced a specified distance when the light beams reach the edge of the film. The thickness of the trace on the high resolution film (300 lines/mm) is only 0.1 mm.

The fundamental reason for the wide use of strong-motion systems consisting of pendulum seismometers and heavily overdamped galvanometers

is the general preference for displacement seismographs with a flat response and the development only recently of a compact high-frequency accelerograph of good quality (the SSRZ) and of a torsion seismometer (the UAR models have low sensitivity, an unreliable trigger, can record only two events, and weigh 50 kg). Work in the late 1960s on the torsion seismometer indicates future application of this approach to accelerometer construction, an approach which is standard in U.S. accelerometer design.

The basic disadvantage of piezoelectric accelerometers, such as the APT-1 and AP-2M, which are finding increased application in Soviet strong-motion systems, is that the maximum period of recordable accelerations at constant sensitivity is proportional to the capacitance of the sensor, while the sensitivity of the accelerometer is inversely proportional to it. This limitation is removed in parametrically excited piezoelectric accelerometers with a frequency response extending to the lowest frequencies (dc).

Soviet seismologists have apparently not developed strong-motion instruments that record on analog magnetic tape. This can be partially attributed to the fact that such recording* does not represent an improvement in dynamic range over the high-quality photographic recorders widely used in the Soviet Union. A prototype model of a digitally recording strong-motion system has been developed; however, no data are available at the present time.

There is no indication that the technology of the position-feedback force-balance design is being considered in the Soviet Union. Nor are there any references to the possibility of retaining first motion information from triggered systems by means of semiconductor memories, following analog-to-digital conversion. Both technologies have been incorporated in the most modern, although not yet widely used, unattended accelerograph systems in the United States.

The overall Soviet effort in strong-motion engineering has been increasing since the early 1960s, and Soviet seismologists have now succeeded in developing more than adequate strong-motion instruments.

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*This obviously excludes nonlinear magnetic recording, e.g., logarithmic.

However, a problem they face and apparently have not solved is the length of time -- sometimes as much as ten years -- between the design of an instrument and its actual production. The VBP-3, VBP-5, and SM-3 seismometers, SSRZ accelerograph, etc., are still being readied for production. Small-lot production of S5S, OSP, and APT-1 seismometers, ISO-2M light-beam oscillograph, etc., has begun only recently. As a result, demand greatly exceeds supply. Another problem is that many of the strong-motion instruments now being produced in small lots are unreliable and of poor quality.

An interesting fact to come out of this study of Soviet strong-motion instruments is that it was not until 1967 that seismic engineering stations (sets of strong-motion instruments in and near buildings, dams, and other structures) began operating.* Moreover, the total number of these stations -- only 60 -- is minuscule in comparison with U.S. strong-motion networks; in California alone government agencies, universities, and businesses maintain more than 600. As far as could be determined, the Soviets have not attempted to install instrumentation in buildings to measure strains in members or relative displacement between floors.

Another interesting observation is that Soviet seismologists are on occasion unfamiliar with Western developments in strong-motion instruments. They accidentally discovered the "unbalanced galvanometer" seismometer and received several patents for its design, unaware that they had actually rediscovered the well-known torsion seismometer.

This Report describes the current state of the art of Soviet strong-motion and vibration-and-blast seismographs. A general section discusses the goals of Soviet seismologists in developing and deploying these instruments. Also included are: four tables listing the technical specifications of Soviet seismometers and accelerometers used most widely in galvanometrically recording strong-motion seismographs; a description of recorders; characteristics of four of the most widely used strong-motion instruments; and specifications of direct-recording, three-component seismograph systems. Sections that follow deal with the GB-III and GB-IV

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*See Appendix B.

galvanometers and with six light-beam and electrostatic oscillographs used in strong-motion and vibration-and-blast seismographs. Also described are seismometers and accelerometers and some of the systems formed by coupling them with light-beam oscillographs, two- and three-component mechanically or optically recording seismograph units, and some of the older vibration-and-blast seismometers and accelerometers. A fifth section treats auxiliary equipment, including seismic triggers. Appendix A describes the Soviet MSK-64 intensity scale, and Appendix B discusses the network of strong-motion seismographs and seismoscopes set up in buildings, dams, and other structures.

In addition to the references listed in the bibliography, dozens of other papers were used to evaluate the validity of the data -- some of it contradictory -- that had appeared in earlier papers, and to obtain information on improvements made on earlier models. Whenever possible, the technical specifications given in this Report refer to the latest models of the strong-motion and vibration-and-blast seismographs.

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CONTENTS

I. GENERAL

This Report describes new, recently modified, and older but still widely used Soviet strong-motion and vibration-and-blast seismographs. These instruments are used in seismology to register seismic waves from strong earthquakes and in seismic engineering to monitor the structural vibrations of dams, buildings, and adjacent ground and the explosion-generated vibrations in the immediate vicinity of blasts. Based on data published in Soviet seismological literature before March 1975 and on specifications and certificates of authorship granted for new instruments, the Report discusses all of the most important strong-motion and vibration-and-blast seismographs, seismograph components, and related equipment in recent use. Owing to the time lag between the development of an instrument and publication of its description, most of the information probably reflects the status of Soviet strong-motion and vibration-and-blast seismographs in use and under development during the period 1971-1972.

Strong earthquakes of intensity $I \geq III^*$ are recorded by strong-motion instruments of the Unified Seismic Observation System (ESSN), the network of permanent seismographic stations located mostly in seismic areas of the Soviet Union, and by temporary stations set up within the epicentral zones of recent strong and destructive earthquakes [1].

According to a program proposed in 1965 [2,3], all ESSN seismographic stations were to be equipped with sets of standard strong-motion instruments. The selection of the necessary equipment was based on the following considerations:

1. Each ESSN station should be capable of recording all earthquakes having surface wave magnitudes $M \geq 4$ originating at $\Delta = 15$ to 1000 km. As a rule, such events should be recorded by two sets of instruments.
2. Seismic instruments should record the spectrum of ground motion (up to period $T \simeq 10$ sec in the case of displacement and up to approximately $T = 1$ sec in the case of acceleration).

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*The intensity scales are discussed in Appendix A.

3. First priority should be given to the installation of instruments in locations where they can record all earthquakes expected to occur at least once during a century, and second priority to recording seismic events expected at least once in ten centuries.

Although this original, fairly inflexible plan specifying the sets of instruments to be installed at a particular ESSN station is not being implemented, Soviet seismologists have succeeded in developing excellent strong-motion instruments, which are gradually being installed at certain ESSN and temporary seismographic stations. Considerable emphasis has also been placed on organizing and equipping stations intended for seismic engineering applications. According to [4], 60 such stations, equipped with 1500 strong-motion instruments and seismoscopes, were in operation in the Soviet Union in early 1973.

Some recent data on the numbers of strong-motion and vibration-and-blast seismographs operating in the Soviet Union in 1972 were supplied by Soviet seismologists at the International Symposium on Strong Earthquake Motion held in Mexico City from August 14 to August 18, 1972. As of early 1972 the following instruments were deployed:*

1. 30 of the older SMTR, continuously recording, horizontal-component systems;
2. 50 of the recently developed SSRZ three-component systems operating in standby mode;
3. 94 strong-motion systems consisting of S5S seismometers and ISO-2M light-beam oscillographs operating in standby mode.

Soviet strong-motion instruments consist typically of (1) two- or three-component strong-motion systems with direct mechanical or optical registration; (2) electromagnetic displacement and velocity seismographs with galvanometric registration; or (3) photographically recording accelerographs of various types (piezoelectric, pendulum, torsion, etc.).

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*This does not include the 1500 strong-motion instruments and seismoscopes installed at 60 engineering stations (see Appendix B).

These systems and components are described in the text. The most important technical specifications of the seismometers and accelerometers and of the light-beam oscillographs with which they are used are summarized in Tables 1 and 2, respectively. The technical specification of the widely used galvanometrically recording systems consisting of S5S, VBP-3, OSP, or APT-1 seismometers or accelerometers in conjunction with an ISO-2M light-beam oscillograph are shown in Table 3. Table 4 gives the important parameters of the three-component systems with direct mechanical and optical registration. These data were compiled from the references given later on in the text under each type of seismograph or its components.

Table 1

TECHNICAL SPECIFICATIONS OF SEISMOMETERS AND ACCELEROMETERS USED MOST WIDELY IN GALVANOMETRICALLY RECORDING STRONG-MOTION INSTRUMENTS

Seismometer	T_s (sec)	D_s[a]	Reduced Length (cm)	A_{min} to A_{max}[b] (mm)	Frequency Range (Hz)	S_{coil}[c] [V/(m/sec)]	Weight (kg)
VEGIK	0.7-2	0.6	9.7	10^{-4} - 2	1.0 - 100	20	10
SM-2M	0.7-2	0.6	9	10^{-4} - 3	0.7 - 100	37	5.5
SM-3	0.7-3	0.6	8	10^{-4} - 5	0.5 - 100	18	5.5
S5S	1-5	0.6	42	10^{-5} - 15	0.2 - 100	13	11
VBP-3	0.4-2	0.7	65	1 - 100	1 - 100	0.1	9.8
VBP-5	2	0.5	100	1 - 200	1 - 100	0.08	10.4
OSP-1	0.2	7	(d)	10^{-2} - 100 125[f]	0.7 - 35	15[e]	4.6
OSP-2	0.16	15	(d)	-- 350[f]	0.4 - 94	11[e]	--

Accelerometer (piezoelectric)	f_s (kHz)	Maximum Acceleration (g)	Frequency Range (Hz)	Accelerometer Sensitivity (V/g)	Weight (kg)
AP-2M	2	1.5	0.1 - 500	≥ 1.0	--
APT-1	1.5	2	0.15 - 500	0.5	4.6

[a]Fraction of critical damping.

[b]A_{min} to A_{max} is the range of recordable, peak-to-peak, ground displacement amplitudes.

[c]Coil sensitivity (S_{coil}) is the coil output for a motion (velocity in m/sec) of the center of oscillation of the pendulum (the steady point of the pendulum for high-frequency motion). Coil sensitivity can be converted to the generator constant by multiplying it by the reduced length and dividing by the distance between the hinge and the coil.

[d]Not applicable.

[e]Generator constant and not coil sensitivity.

[f]Maximum recordable peak-to-peak ground velocity amplitude in cm/sec.

Table 2

TECHNICAL SPECIFICATIONS OF RECORDERS USED IN SOVIET STRONG-MOTION INSTRUMENTS

Recorder	Type and Description	Optical Lever (cm)	Number of Channels and Galvo Type	Recording Medium: Type and Size	Recording Speed (mm/sec)	Dimensions (cm^3) and Weight (kg)	Power Supply
ISO-2M	Light-beam self-actuating with automatic reset. Records 5 events of 60 sec duration. Loss of motion < 0.2 sec.	15	6 GB-IV-C-3 GB-IV-S-10	Photo film 35mm x 1.6m	5 or 10	26x20x30 12 kg	12 V dc 6 W
OSB-IMp	Light-beam continuously recording oscillograph. Transverse motion capability with drum.	30	3-6 GB-III or GB-IV	Photo paper 12cm x 45cm (drum) 12cm x 12m (film cassette)	0.156-64	59x30x28 20 kg	220 V ac 30 W
N-700 (POB-14M)	Light-beam continuously recording oscillograph[a]	30	7-14 GB-III or GB-IV	Photo paper 12cm x 12m	2.5,10,40, 160,640, 2500	47x24x29 18 kg	27 V dc or 24 V ac 5 A
POB-12M	Light-beam continuously recording oscillograph[a]	42	6-12 GB-III or GB-IV	Photo paper 12cm x 12m	0.15-8000	57x32x25 18 kg	27 V dc 24 V ac 5 A
PZZ (modified POB-12M model)	Self-actuating with automatic reset. Low-gain PZZ channels are used primarily with standard, broadband SKD seismographs.	42	6-12 GB-III-0.8 (with SKD) GB-IV	Photo paper 12cm x 12m	15,30	57x32x25 16 kg	12 V dc 25 W
PEO-I	Electrostatic, self-actuating with automatic reset. No loss of first motion.	15	3-6 GB-III or GB-IV	Plain paper 12cm x 20m	0.75,3,12, 48, or 4,8,16,32, 64,128	50x30x30 27 kg	220 V ac 50-400 W

[a] Can also be converted to standby operation by means of FEPU or PU-1 seismic triggers.

Table 3 [5]

TECHNICAL SPECIFICATIONS OF FREQUENTLY USED STRONG-MOTION SYSTEMS WITH GALVANOMETRIC RECORDING

Specifications	S5S and ISO-2M		VBP-3 and ISO-2M		OSP and ISO-2M		APT-1 and ISO-2M	
T_s (sec)	5		2		0.2		0.001	
Recording Speed (mm/sec)	5 or 10		5 or 10		5 or 10		5 or 10	
Recording Time for Each of Five Events (sec)	30 or 60		30 or 60		30 or 60		30 or 60	
Number of Galvos and Galvo Type	6 GB-IV-C-3	6 GB-IV-S-10	6 GB-IV-C-3	6 GB-IV-S-10	6 GB-IV-C-3	6 GB-IV-S-10	6 GB-IV-C-3	6 GB-IV-S-10
Natural Frequency (Hz)	120	10	120	10	120	10	120	10
Response	Vel	Displ	Vel	Displ	Accel	Vel	Accel	Vel
Range of Sensitivities ($S_x, S_{\dot{x}}, S_{\ddot{x}}$) at Recorder Output	0.2-40 mm/(cm/sec)	0.2-40 mm/mm	0.03-6 mm/(cm/sec)	0.1-20 mm/mm	2-400 mm/g	0.03-6 mm/(cm/sec)	2-400 mm/g	0.03-6 mm/(cm/sec)
Frequency Range[a] (Hz)	0.25-30	1-30	0.7-30	1-30	0.7-30	1-30	0.2-30	1-30

[a]At the 0.9 level of maximum magnification.

Table 4

DIRECT RECORDING STRONG-MOTION SEISMOGRAPH SYSTEMS

	Accelerographs	f_s (Hz)	D_s [a]	$S_{\ddot{x}}$ (mm/g)	Maximum Acceleration (g)	Dynamic Range (dB)	Recording Medium	Recording Speed (cm/sec)	Weight (kg)
UAR	3-component, self-actuating accelerograph with automatic reset. Records 2 events of I ≥ VI of 30-sec duration each.	25	0.7	14	2	35	60 mm photo paper	1.0	50
SSRZ	3-component, self-actuating accelerograph with automatic reset. Records 10 events of I ≥ III of 50-sec duration each.	20,30 or 35	0.6	12,15,or 40-50	3	40	60 mm photo film	0.3,0.6	21 (plus power supply-13 kg)

	Velocity Seismographs	f_s (Hz)	D_s [a]	$S_{\dot{x}}$ [mm/(cm/sec)]	Maximum Velocity	Dynamic Range (dB)	Recording Medium	Recording Speed (cm/sec)	Weight (kg)
SSRZ	3-component, self-actuating velocity seismograph with automatic reset. Records 10 events of I ≥ III of 50-sec duration each.	10	30	0.24	--	40	70 mm photo film	0.3,0.6	21 + 13

Table 4 (cont.)

	Displacement Seismographs	T_s (sec)	D_s[a]	v_{max}	Maximum Displacement (cm)	Dynamic Range (dB)	Recording Medium	Recording Speed (cm/sec)	Weight (kg)
MTR	2-component, horizontal-motion displacement seismograph. Continuous recording of up to 72 hrs	5	0.4-0.5	7	1.5	--	Smoked or heat sensitive paper	3, 6	--
SS-5	3-component displacement seismograph with a microphoto-recording assembly capable of up to 1 month of continuous registration	1-3	0.3-1	0.1-2	±10	--	70 mm photo film	1.8, 3.6	--

[a]Fraction of critical damping.

II. GB-III AND GB-IV GALVANOMETERS [5,6,7]

The GB-III and GB-IV are the two basic galvanometer types used widely in seismology and seismic engineering as the sensing elements of light-beam oscillographs. Each type includes several series that differ in their natural frequency, current sensitivity, coil resistance, and other parameters. Soviet seismologists separate all galvanometers used in seismic applications into two groups: (a) high-frequency galvanometers with the natural frequency $f_g \gtrsim 30$ Hz and optimal damping of about 0.7 and (b) heavily overdamped galvanometers with $f_g \lesssim 15$ Hz, optimal damping as high as 25 to 30 times critical damping, and high coil resistance. The response of high-frequency galvanometers extends between approximately one-half of its natural frequency and dc; that of a heavily damped galvanometer is symmetric about its natural frequency.

The GB-III and GB-IV galvanometers are intended for use primarily with galvanometrically recording strong-motion instruments. The GB-III and GB-IV are interchangeable, with two GB-IV galvanometers used for each GB-III. The smaller size of the GB-IV is achieved by using a narrower, lighter coil than that used in the GB-III. When both GB-III and GB-IV galvanometers with the same natural frequency are available, the Soviets prefer to use GB-IVs. The latter are smaller, more sensitive, and have a lower moment of inertia. However, GB-IV galvanometers with a natural frequency below 5 Hz are unavailable, and GB-IIIs have to be used instead. According to [8], low-frequency GB-IV galvanometers are not manufactured because Soviet industry is unable to fabricate narrow suspensions with a sufficiently low torsion constant.

A schematic drawing of the GB-III and GB-IV galvanometers is shown in Fig. 1. Table 5 gives the technical specifications of galvanometers recommended for use in seismic engineering and seismology. (In this table f_g is the natural frequency of the galvanometers, C_i is the current sensitivity, R_g is the coil resistance, R is the external resistance at 0.7 critical damping, I_{max} is the maximum current, and K_g is the moment of inertia.)

GB-III and GB-IV galvanometers are used in ISO-2M, OSB-IMp, POB-12M, N-700, PZZ, and other types of light-beam oscillographs.

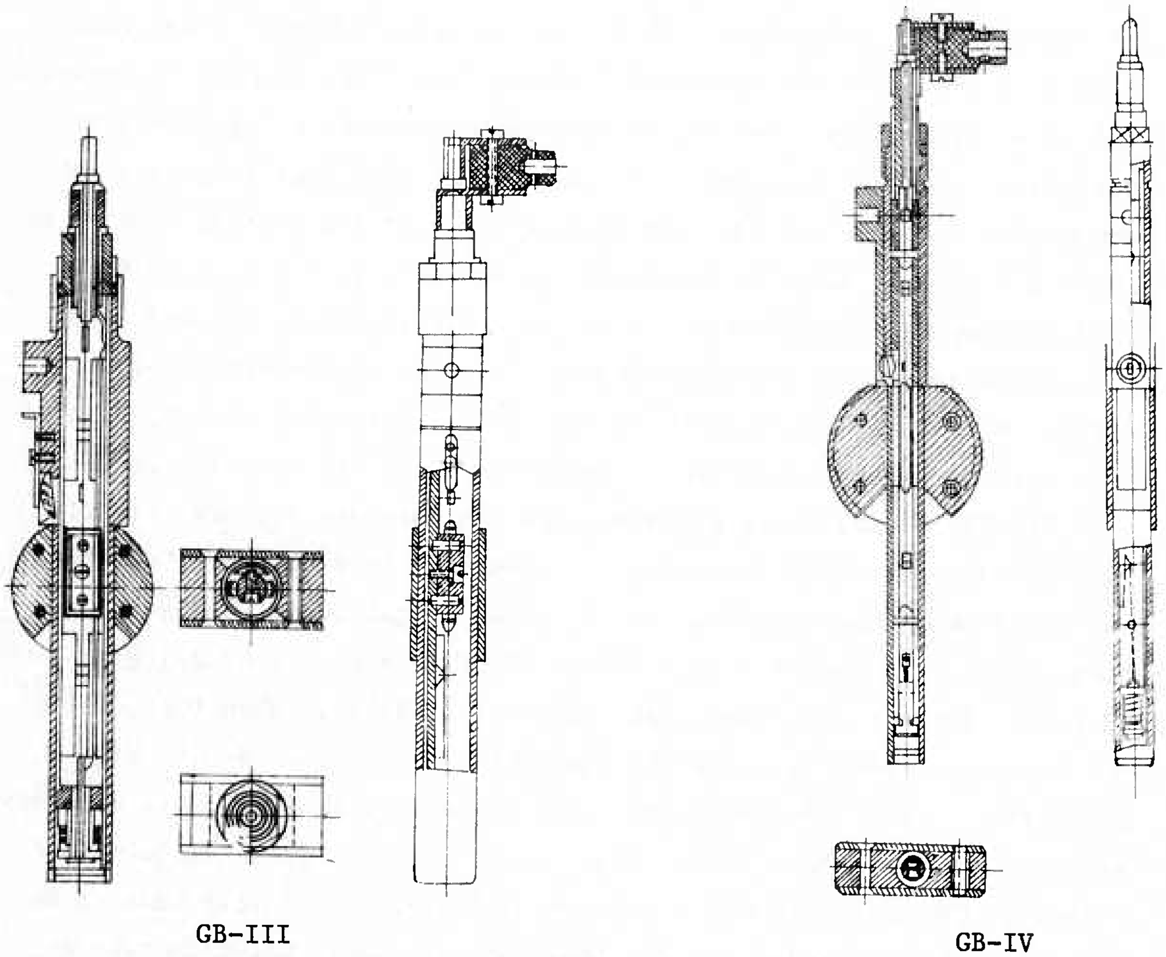

Fig. 1 -- Schematic drawing of the GB-III and GB-IV galvanometers [6]

Table 5 [5,6,7]

TECHNICAL SPECIFICATIONS OF THE GB-III AND GB-IV GALVANOMETERS

Galvanometer	f_g (Hz)	C_i (A/m at 1m)	R_g (ohms)	R (ohms)	I_{max} (mA)	K_g (kg·m²)
GB-III-B-0.8	0.8	2.5×10^{-9}	52	5000		1.20×10^{-9}
GB-III-B-1	1.25	4.0×10^{-9}	64	6000	0.003	1.15×10^{-9}
GB-III-B-2.5	2.5	1.5×10^{-8}	60	3000	0.011	1.15×10^{-9}
GB-III-B-5	5	6.0×10^{-8}	56	1500	0.044	1.50×10^{-9}
GB-III-B-10	10	2.5×10^{-7}	56	750	0.18	1.15×10^{-9}
GB-III-C-1	1.25	1.6×10^{-9}	400	42000	0.001	--
GB-III-C-2.5	2.5	8.0×10^{-9}	400	19000	0.006	--
GB-III-C-5	5	30.0×10^{-8}	400	9500	0.0022	--
GB-III-C-10	10	1.2×10^{-7}	400	4700	0.09	--
GB-III-BS-0.8	0.8	5.0×10^{-9}	52	800	0.004	1.2×10^{-9}
GB-III-BS-1.0	1.25	1.0×10^{-8}	64	950	0.008	1.15×10^{-9}
GB-III-BS-2.5	2.5	4.0×10^{-8}	60	420	0.03	1.15×10^{-9}
GB-III-BS-2.5	2.5	1.4×10^{-8}	76	360	0.01	0.2×10^{-9}
GB-III-BS-5	5	1.5×10^{-7}	56	220	0.1	1.15×10^{-9}
GB-III-BS-10	10	5.0×10^{-7}	56	110	0.4	1.15×10^{-9}
GB-III-3	5	2×10^{-8}	140	4000	--	1.15×10^{-9}
GB-III-BM-1	1.25	2×10^{-9}	76	4600	--	0.2×10^{-9}
GB-III-BM-2.5	2.5	7×10^{-9}	76	2300	--	0.2×10^{-9}
GB-III-BM-5	5.0	3×10^{-8}	76	1150	--	0.2×10^{-9}
GB-III-BM-10	10.0	1.2×10^{-7}	76	550	--	1.15×10^{-9}
GB-IV-B-1	20-30	1.3×10^{-8}	170.0	3200	--	--
GB-IV-B-2	60	1.0×10^{-7}	170.0	1050	0.04	--
GB-IV-B-3	120	4.0×10^{-7}	170.0	470	0.2	--
GB-IV-C-1	30	2.0×10^{-8}	58.0	1200	0.01	4.5×10^{-12}
GB-IV-C-2	60	1.0×10^{-7}	58.0	350	0.04	4.5×10^{-12}
GB-IV-C-3	120	3.0×10^{-7}	52.0	175	0.2	4.5×10^{-12}
GB-IV-S-5	5	5.0×10^{-9}	78	2600	0.002	1.7×10^{-11}
GB-IV-S-10	10	2.0×10^{-8}	54	1200	0.007	9.4×10^{-12}
GB-IV-S-15	15	5.0×10^{-8}	54	800	0.025	9.4×10^{-12}
GB-IV-SI-5	5	8×10^{-9}	65	5000	--	1.5×10^{-10}
GB-IV-SI-10	10	3×10^{-8}	65	2500	--	1.5×10^{-10}
GB-IV(M-001)	120	4×10^{-7}	54	liq.damp.	--	4.5×10^{-12}

III. RECORDING SYSTEMS

A. ISO-2M SELF-ACTUATING LIGHT-BEAM OSCILLOGRAPH [9,10,11]

The ISO-2M, a portable, six-channel, light-beam oscillograph can be used with any transducer with an electrical output. It was designed primarily for registration of displacements, velocities, or accelerations of the ground or of man-made structures generated by strong earthquakes or explosions. The ISO-2M can operate unattended for up to six months and is capable of recording five separate events of intensity III-VIII. Figure 2 is a schematic drawing of the ISO-2M. The oscillograph is started automatically by an electronic trigger connected to one of the seismometers, with the loss of motion not exceeding 0.2 seconds. An asymmetric multivibrator connected to one of the galvanometers places timing lines on the record at one-second intervals. High-quality optics makes it possible to identify signals with frequencies up to 25 Hz. The ISO-2M is equipped with an event indicator actuated by the trigger and a total-power shut-off mechanism activated at the end of the last recording cycle. The oscillograph is the latest model of the ISO-2M developed in 1963. This model's improved performance was achieved by means of a new suspension (which reduces parasitic modes due to poorly balanced galvanometers), a different 2DKS-7 dc motor with a centripetal velocity control rated at 2000 ± 30 rpm, a single power supply (dry cells or an external dc source), and a new transistorized timing system. The ISO-2M is intended for operation at temperatures between -10°C and +35°C and a relative humidity of up to 80 percent. The technical specifications of the ISO-2M are as follows:

Number of channels	5 recording; 1 timing
Mode of operation	Self-actuating with automatic reset
Optical lever	15 cm
Recording medium	Standard photographic film, 35 mm wide and 1.6 m long
Recording speed	5 or 10 mm/sec

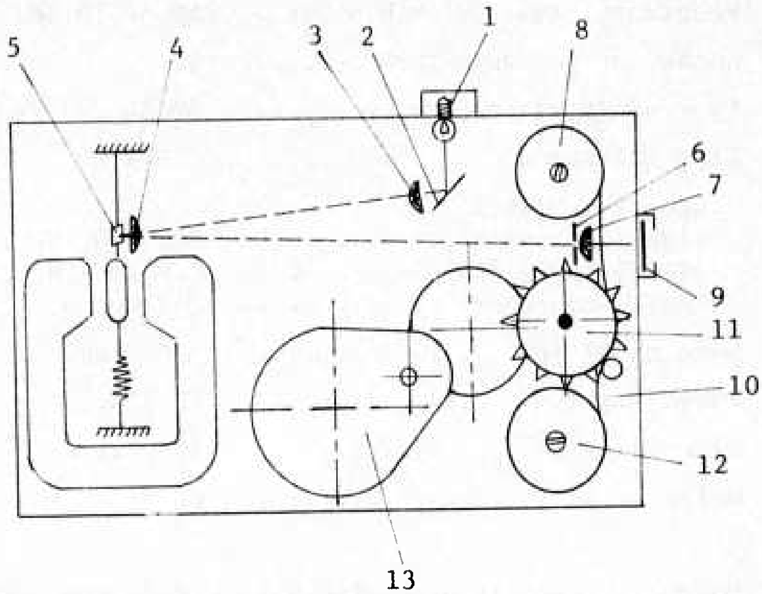

Fig. 2 — Schematic drawing of the ISO-2M light-beam oscillograph [6]
1 - lamp
2 - mirror
3 - cylindrical lens
4 - spherical lens
5 - galvanometer
6 - slit
7 - cylindrical lens
8 - supply reel
9 - screen
10 - photographic film
11 - drive assembly
12 - take-up reel
13 - motor

Number of recordable events	5
Recording time for each event ...	60 or 30 sec
Number of galvanometers	6
Type of galvanometers	GB-IV-B-3 or GB-IV-S-10
Line thickness	< 0.2 mm
Triggering system	
signal strength	50, 100, 200, 400 mV
signal bandwidth	0.6 to 7 Hz
input impedance	≥ 3 kohms
Loss of motion	≤ 0.2 sec
Power supply	12 V dc, 6 W
Dimensions	26 x 20 x 30 cm
Weight	12 kg

The ISO-2M is normally used with S5S, VBP-3, OSP, APT-1, VEGIK, SM-2M, and SM-3 seismometers. The technical specifications of strong-motion systems consisting of S5S, VBP-3, OSP, and APT-1 seismometers and ISO-2M recording oscillographs are summarized in Table 3.

The latest improvement of the oscillograph is the addition of an external reference timing unit which makes it possible to photograph the face of a quartz clock at the end of each event [1]. According to [5], from 60 to 80 ISO-2M light-beam oscillographs are manufactured annually. At the present time, the ISO-2M is most frequently used with the S5S seismometers.

B. OSB-IMp CONTINUOUSLY RECORDING LIGHT-BEAM OSCILLOGRAPH [12]

The OSB-IMp is a portable, light-beam oscillograph designed for continuous three-to-six channel registration on standard 12-cm-wide photographic paper that is either mounted on an enclosed drum or advanced at a uniform speed between the supply and take-up reels of a cassette. It is equipped with a synchronous motor which has to be used with the cassette. The drum, however, can be driven by an external spring drive with a centripetal device for velocity control. The model OSB-IMp is usually used with six GB-IV galvanometers, less frequently with three GB-IIIs. Time marks from an outside clock are printed on paper as breaks

in the lines when a relay briefly disconnects the circuit between the lamp illuminating the galvanometer mirror and the power supply. The oscillograph is equipped with a variable-width diaphragm rather than an automatic spot-brightness control. Figure 3 shows a cross section of the OSB-IMp and Fig. 4, a schematic drawing of its optical system. The OSB-IMp is intended for operation at temperatures between -10°C and +30°C and a relative humidity of up to 80 percent. The technical specifications of the OSB-IMp are as follows:

Number of channels	3 to 6
Mode of operation	Continuous
Optical lever	30 cm
Recording medium	Photographic paper 12 cm wide and 45 cm long for a drum and 10 m long for a film cassette
Recording speed	
drum with motor	0.25, 0.5, 1, 2, 4, 8, 16, 32, 64 mm/sec
drum with spring drive	0.125, 0.25, 0.5, 1, 2 mm/sec
cassette with motor	0.156, 0.312, 0.625, 1.25, 2.5, 5, 10, 20, 40 mm/sec
Translation rates	
drum	0.5, 1, 2 mm/rev
cassette	0
Record duration	
drum with motor	8 hrs at 1 mm/sec and 0.5 mm/rev
drum with spring drive	8 hrs
Power supply	220 V ac, 30 W
with spring drive	3 V dc, 0.5 W
Dimensions	59 x 30 x 28 cm
Weight	20 kg

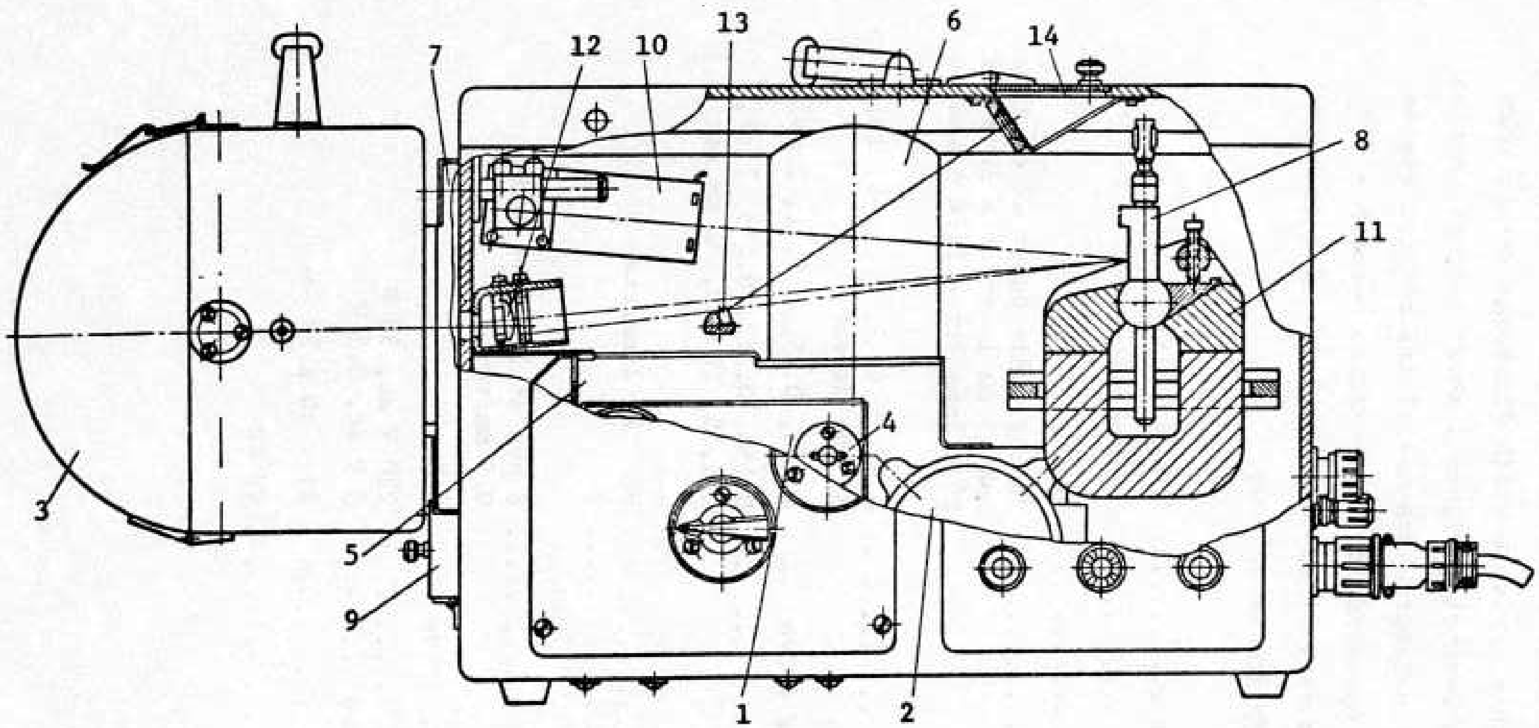

Fig. 3 -- Cross-sectional view of the OSB-IMp light-beam oscillograph [12]

1 - spring drive
2 - synchronous motor
3 - drum
4 - winding mechanism
5 - gear box
6 - centripetal device for velocity control
7 - transverse motion carriage
8 - galvanometer
9 - interchangeable transverse motion gears
10 - light source
11 - galvanometer bank
12 - cylindrical lens
13 - mirror
14 - trace-viewing window

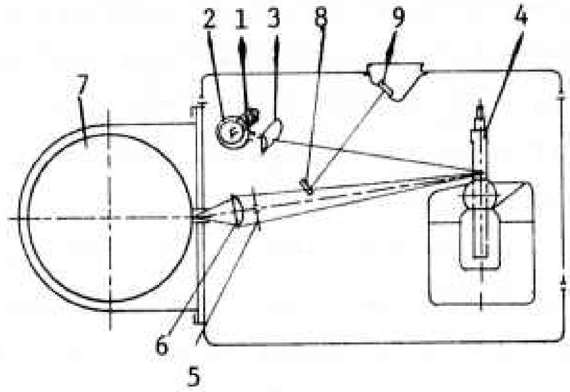

Fig. 4 -- Schematic drawing of the optical system of the OSB-IMp [12]

1 - lamp
2 - shielding cap
3 - cylindrical lens (probably oriented vertically)
4 - galvanometer with a spherical lens and a mirror
5 - variable width diaphragm
6 - cylindrical lens
7 - drum
8 - mirror
9 - viewing window screen

C. POB-12M LIGHT-BEAM OSCILLOGRAPH [6,13]

The POB-12M, a portable, six-to-twelve channel light-beam oscillograph, was developed in the early 1950s and has been produced on request for the last 15 years. The POB-12M is used for photographic recording of any processes that are converted into an electrical output, but is intended primarily for use in engineering seismology. It is equipped with six GB-III or twelve GB-IV galvanometers. Time marks on the record are printed every 0.1 or 0.005 seconds. The externally mounted drum or cassette makes it possible to use different lengths of photographic paper and to record at a wide range of speeds. A schematic drawing of the POB-12M oscillograph is shown in Fig. 5.

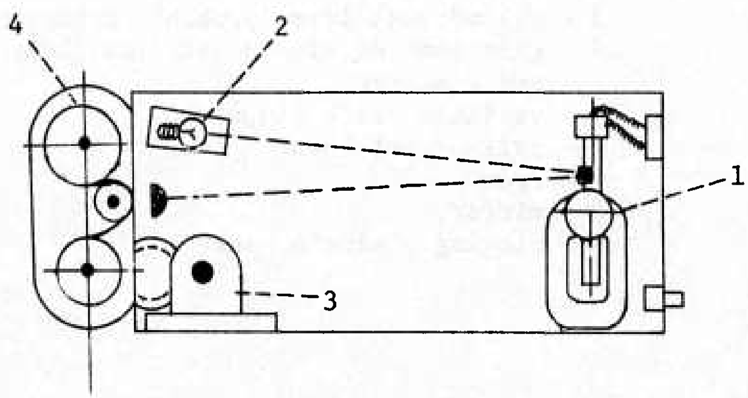

Fig. 5 -- Schematic drawing of the POB-12M light-beam oscillograph [6]
1 - galvanometer
2 - lamp
3 - motor
4 - film cassette

The POB-12M is intended for operation under stationary and field conditions at temperatures between -10°C and +30°C and a relative humidity of up to 80 percent.

The technical specifications of the POB-12M light-beam oscillograph are as follows:

Number of channels	6 to 12
Mode of operation	Continuous or trigger-actuated with automatic reset
Optical lever	42 cm
Recording medium	Photographic paper, 12 cm wide and up to 12 m long
Recording speed	
cassette for low frequency recording	0.15, 0.3, 1, 2, 6, 12 mm/sec
cassette for high frequency recording	20, 40, 125, 250, 750, 1500 mm/sec
drum for high frequency recording	111, 222, 666, 1333, 4000, 8000 mm/sec
Time marks	10 or 200 pps
Power supply	27 V dc, 24 V ac, 5 A
Dimensions	57 x 32 x 25 cm
Weight	18 kg

The POB-12M can be converted to a standby mode of operation by means of the older FEPU or the very recent PU-1 seismic triggers described in Sections V-B and V-C.

D. N-700 (POB-14M) LIGHT-BEAM OSCILLOGRAPH [14]

The POB-14M portable light-beam oscillograph, developed in the early 1950s and produced in fairly large quantities since 1958 under the name N-700, has found wide application in both seismic exploration and engineering seismology. It is the cheapest and most widely used Soviet light-beam oscillograph, with more than 25,000 units manufactured during a period of approximately 14 years. The N-700 is used for photographic recording of any processes in the frequency range from 3000 Hz to dc, converted into an electrical output. When used with strong-motion instruments it is equipped with seven GB-III or fourteen GB-IV (M-001) d'Arsonval galvanometers. Time marks are recorded every 0.1 or 0.005 seconds. The externally mounted drum or cassette makes it possible to use different lengths of photographic paper and to record at a wide range

of speeds. According to [2], the maximum full-scale deflection of the beam recorded on photographic paper is ±3 cm when the oscillograph is used with GB-III galvanometers and ±1.5 cm when used with GB-IV galvanometers. The minimum resolvable double amplitude is 0.5 mm. The N-700 recorder is intended for operation under stationary and field conditions at temperatures between -10°C and +30°C and a relative humidity of up to 80 percent. The A-001 drum cassette for registration of short-duration, high-frequency events is available on special order. The A-002 attachment, which provides visual registration without the loss of first motion, is also available. It consists of a loop of paper covered with a layer of phosphor which retains the image of the light beams from the galvanometers of the N-700 oscillograph. When triggered by a seismic signal above a certain threshold, it comes into contact with the photographic film and transfers the image onto the film. A more detailed description of the A-002 attachment is given in Section V-D. The technical specifications of the N-700 are as follows:

Number of channels	7 to 14
Mode of operation	Continuous or trigger-actuated with automatic reset
Optical lever	30 cm
Recording medium	Photographic paper 120 mm wide and 12 m long (standard length)
Recording speed	2.5, 10, 40, 160, 640, 500 mm/sec (10 mm/sec is the most frequently used speed in engineering seismology)
Time marks	10 or 200 pps
Maximum pen excursion	
with GB-III galvos	± 3 cm
with GB-IV galvos	1.5 cm
Power supply	27 V dc, 24 V ac, 5 A
Dimensions	47 x 24 x 29 cm
Weight	18 kg

The N-700 can be converted to a standby mode of operation by means of the older type FEPU or the very recent PU-1 seismic trigger described in Sections V-B and V-C.

E. PZZ LIGHT-BEAM OSCILLOGRAPH [15]

The PZZ is a slightly modified model of the POB-12M light-beam oscillograph and is intended primarily for separate recording, at low gain, of seismic data acquired by the standard, broad-band SKD seismographs being installed at Soviet base seismographic stations. The PZZ is actuated and automatically reset by the photoelectric AUZ trigger (described in Section V-A) that is used at the Soviet permanent seismographic stations. The three channels are connected to the calibration coils of SKD seismometers through a shunt box which reduces the seismograph magnification. When used with SKD seismometers the PZZ is equipped with three GB-III-B-0.8 galvanometers. The technical specifications of the PZZ recorder are as follows:

Number of channels	3 to 6
Mode of operation	AUZ trigger-actuated with automatic reset
Duration of each cycle	30 min and multiples of 30 min
Recording medium	Photographic paper, 12 cm wide and 12 m long
Recording speed	15, 30 mm/min
Galvanometers	
number	6 to 12
type	GB-III-0.8 (with SKD) GB-IV
Power supply	12 V dc, 25 W
Dimensions	57 x 32 x 25 cm
Weight	16 kg

F. PEO-I ELECTROSTATIC OSCILLOGRAPH [6,16,17]

The PEO-I (see Fig. 6), a compact, three-to-six channel, electrostatic light-beam oscillograph, records on 120-mm-wide, plain, strip-chart paper. Developed in 1969-1970, the PEO-I is apparently intended to

replace similar earlier models of electrostatic recorders, the SEO-I, N-001 (SEO-II), and the A-002 attachment to the N-700 light-beam oscillograph, which used low-sensitivity paper that required toxic developers.

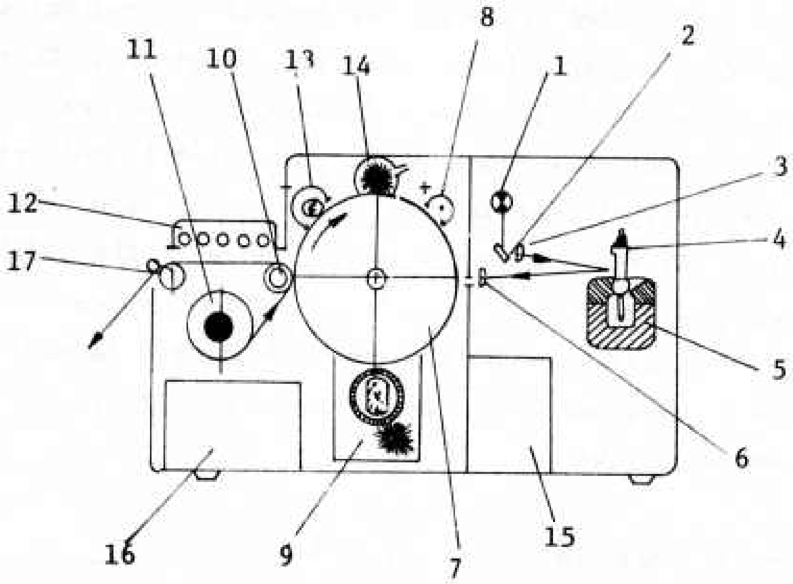

Fig. 6 -- Schematic drawing of the PEO-I electrostatic light-beam oscillograph [6]

1 - lamp
2 - mirror
3 - lens
4 - galvanometer
5 - magnet assembly
6 - lens
7 - metallic drum with layer of selenium or arsenic-selenium
8 - roller to charge the drum
9 - developing device
10 - transfer roller
11 - supply drum
12 - fusing device
13 - lamp
14 - cleaning device
15 - vacuum pump
16 - mechanical components
17 - driving roller

The PEO-I is operated in a standby mode and actuated without a loss of motion by an unspecified electronic trigger. Its metallic drum, driven at a uniform speed by an electric motor, is covered with a layer of selenium or arsenic-selenium. The light beams reflected from the galvanometer mirrors establish electrostatic patterns of trace images on the selenium layer. When actuated, the images are automatically developed by charged dry powder and then transferred and heat fused onto plain strip-chart paper. The developed paper is either wound on the take-up reel or fed outside for quick processing of the seismogram. The recorder is intended for operation under stationary and field conditions at temperatures between +15°C and +30°C and a relative humidity of up to 80 percent. The technical specifications of the PEO-I are as follows:

Number of channels	3 to 6 [6]; 6 to 12 [5]
Mode of operation	Self-actuating with no loss of motion
Frequency range	0 to 200 Hz
Maximum pen excursion	± 3 cm
Optical lever	15 cm
Recording medium	Plain paper, 12 cm wide and 20 m long
Recording speed	0.75, 3, 12, 48 mm/sec [6] 4, 8, 16, 32, 64, 128 mm/sec [5]
Translation rate	0
Power supply	220 V ac, 300 W
Dimensions	50 x 30 x 30 cm
Weight	27 kg

IV. SEISMOMETERS, ACCELEROMETERS, SEISMOGRAPHS, AND ACCELEROGRAPHS

A. VBP-3 [6,18,19]

The VBP-3 (see Fig. 7) is one of the older Soviet strong-motion and blast seismometers designed for galvanometric recording of either vertical or horizontal components of displacement with amplitudes between 1 mm and 10 cm in the frequency range 1 to 100 Hz at a maximum acceleration of 1 g. It is a pendulum type instrument with an electromagnetic, moving-coil transducer with electromagnetic damping. The period of the VBP-3 is adjustable between 0.5 and 2 sec. Large reduced pendulum length is achieved by dividing the inertial mass into two almost equal parts and placing them symmetrically on the opposite sides of the axis of rotation. The pendulum consists of a rectangular frame with three small holes drilled in one of its shorter sides (one of the two inertial masses). Two cylindrical brass rods extending outward from the centers of the longer sides of the pendulum constitute the axis of rotation. The aluminum pendulum is installed in ball bearings mounted on the outer ends of the brass rods. A small rectangular frame inside the pendulum located symmetrically with respect to their common axis of rotation serves as both the coil former and the damper. The rectangular frame fits into the gaps between the core and pole pieces of the permanent magnet.

The vertical seismometer is equipped with two steel plates mounted on the cylindrical rods forming the axis of rotation. The steel plates located outside the magnet tend to align themselves along the lines of force and thus compensate the force of gravity and provide the restoring quasi-elastic force. Since the two steel plates act as a spring whose stiffness is determined by the distance between the plates and the magnet, the pendulum period of the vertical seismometer can be adjusted by moving the plates along the axis of rotation. The absence of a gravity-compensating spring makes the vertical seismometer insensitive to temperature changes.

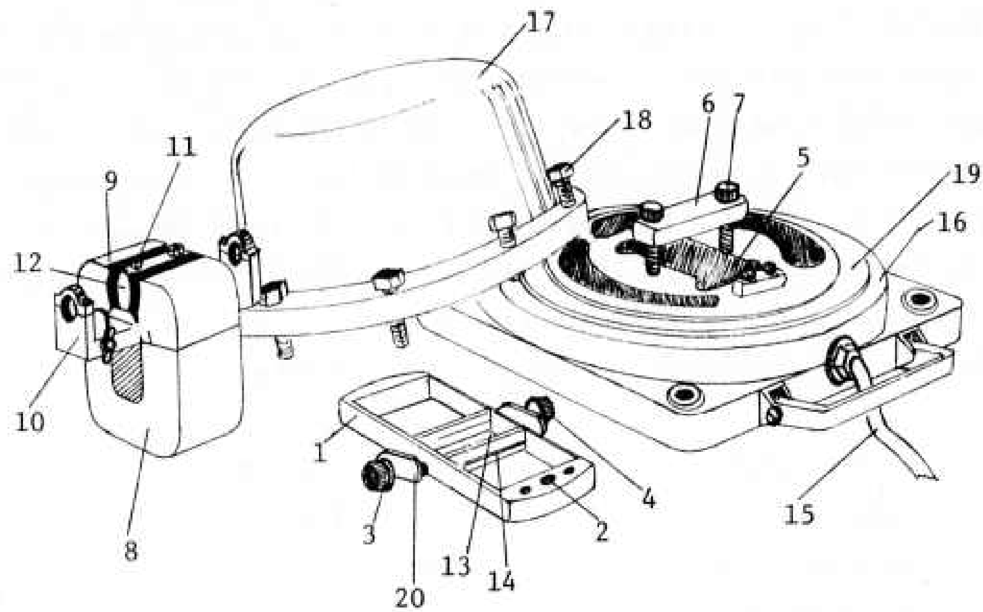

Fig. 7 -- Schematic drawing of the VBP-3 seismometer [6]

1 - pendulum
2 - holes in the pendulum
3 - cylindrical rod forming the axis of rotation
4 - ball bearing
5 - recess
6 - crosspiece
7 - bolt
8 - permanent magnet
9 - pole piece
10 - bracket
11 - guides
12 - core
13 - coil former and damper
14 - coil
15 - cable
16 - gasket
17 - cover
18 - bolts
19 - rubber gasket
20 - steel plate

The VBP-3 can be changed from a vertical to a horizontal seismometer by rotating the seismometer assembly 90° around the horizontal axis, making sure that the heavier inertial mass is below the lighter mass and removing the two steel plates. Simple adjustment of the steel plates makes it possible for the VBP-3 to record ground motion at any angle to the vertical. The VBP-3 is intended for operation at temperatures between -10°C and +40°C and is watertight to 10 m of water. The technical specifications of the VBP-3 are as follows:

Natural period	1.6 sec (nominal)
Damping factor	0.7 to 0.8
Reduced length	0.65 m
Inertial mass	110 gm
Signal coil sensitivity	0.1 V/(m/sec)
Signal coil resistance	55 ohms
Moment of inertia	2.3×10^{-4} kg·m^2
Dimensions	15 x 23 x 23 cm
Weight	9.8 kg

The technical specifications of a strong-motion system consisting of a VBP-3 seismometer and an ISO-2M recording system are given in Table 3. A magnification curve of a system consisting of a VBP-3 seismometer and an N-700 light-beam oscillograph equipped with GB-IV galvanometers is shown in Fig. 8. Figure 9 shows magnification curves of a VBP-3 and a VBP-5 coupled to the GB-III-3 galvanometers of an N-700 oscillograph.

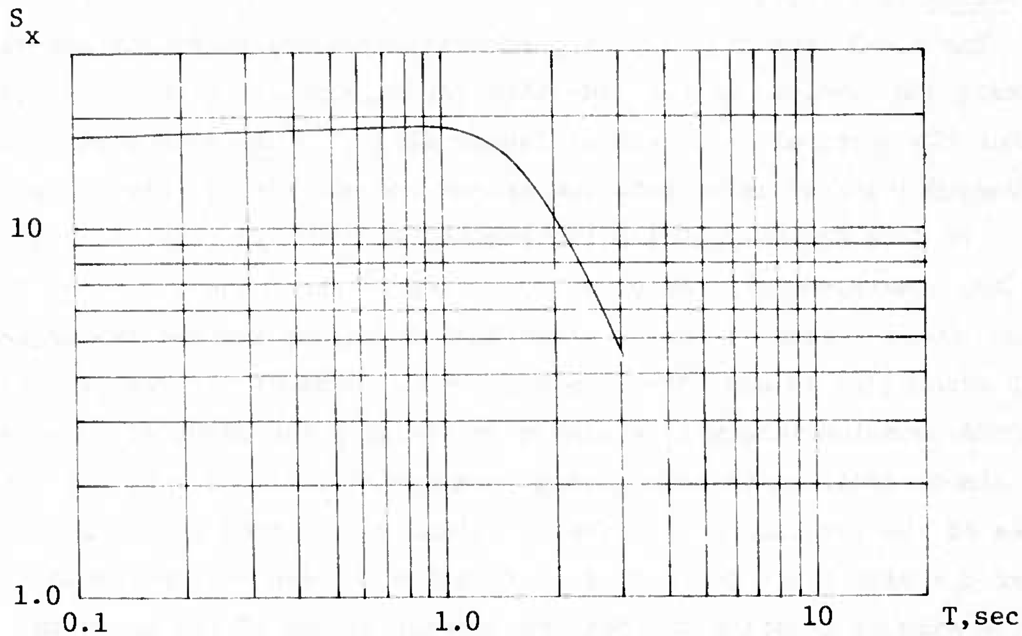

Fig. 8 -- Magnification curve of a three-component strong-motion system consisting of VBP-3 seismometers and an N-700 light-beam oscillograph with a heavily damped GB-IV galvanometer [20]

$T_s = 1.6$ sec

$D_s = 0.6$

$T_g = 0.206$ sec

$D_g = 15$

$\sigma^2 = 0.0152$

$\bar{v} = 18$

B. VBP-5 [21,22,23]

The VBP-5 (see Fig. 10) is a strong-motion and vibration-and-blast seismograph designed in the mid-1960s for galvanometric recording of either the vertical component of linear displacements with amplitudes between 0.1 and 20 cm or rotation around the horizontal axis of up to 10°. It is a double-pendulum instrument, with two moving-coil transducers and two electromagnetic dampers, operating in the frequency range between 1 and 100 Hz. Each of the two identical pendulums and the two magnet-coil assemblies of the VBP-5 are similar to those of the VBP-3. Large reduced pendulum length is achieved by dividing the inertial mass into two almost equal parts and placing them symmetrically on the opposite sides of the rotation axis. The pendulums are mounted parallel to each other but with their centers of oscillation located on the opposite sides of the axis of rotation so that the heavier masses of the pendulums are facing in opposite directions. While the output of the VBP-5 is proportional to linear or angular velocity, the signal is integrated by the GB-III overdamped galvanometer usually used with this seismometer. The change in response of the VBP-5 seismometer from linear to angular displacement or vice versa is accomplished by changing electrical connections between the seismometer coils and the galvanometer to add or subtract the two signals.

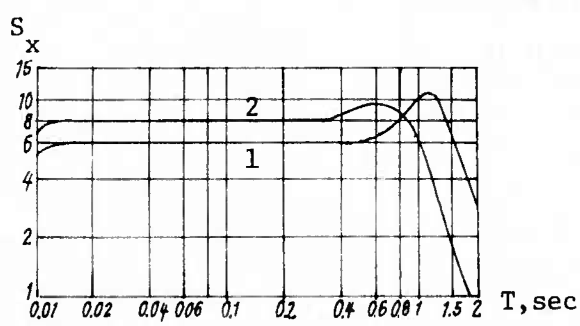

Fig. 9 -- Magnification curves of the VBP-5 (1) and VBP-3 (2) seismometers coupled to GB-III-3 galvanometers of the N-700 light-beam oscillograph with unspecified instrumental constants [24]

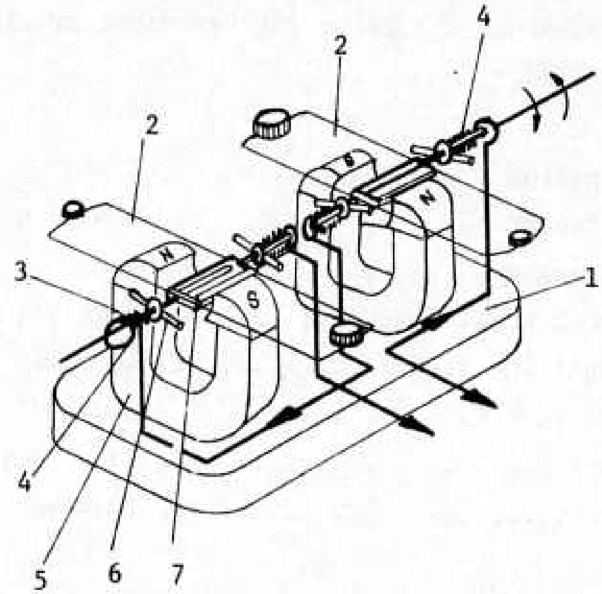

Fig. 10 -- Schematic drawing of the VBP-5 seismometer [6]
1 - base
2 - pendulum
3 - axes of rotation
4 - ball bearings
5 - permanent magnets with pole pieces
6 - steel plate
7 - damping plate with signal coil

Each aluminum pendulum is installed in ball bearings mounted on the outer ends of the brass rods. A small rectangular frame inside the pendulum located symmetrically with respect to their common axis of rotation serves as both the coil former and the damper. The rectangular frame fits into the gaps between the core and pole pieces of the permanent magnet. The vertical seismometer is equipped with two steel plates mounted on the cylindrical rods forming the axis of rotation of each pendulum. The steel plates located outside the magnet tend to align themselves along the lines of force and thus compensate the force of gravity and provide the restoring quasi-elastic force. Since the two steel plates act as a spring whose stiffness is determined by the distance between the plates and the magnet, the pendulum period of the vertical seismometer can be adjusted by moving the plates along the axis of rotation. The absence of a gravity compensating spring makes the vertical seismometer

insensitive to temperature changes. The technical specifications of the VBP-5 are as follows:

Natural period	2 sec
Damping factor	0.6 to 0.7
Reduced length	1 m
Signal coil sensitivity	0.08 V/(m/sec)
Signal coil resistance	40 ohms
Moment of inertia	3×10^{-4} kg·m^2
Dimensions	29 x 18 x 15 cm
Weight	10.4 kg

If the two pendulums of the VBP-5 are completely identical, the seismometer will respond to vertical displacements only, and not to rotation in the plane of oscillation of the pendulums, or vice versa. The VBP-5 is insensitive to rotation around the vertical axis.

The magnification curve of a system consisting of a VBP-5 seismometer and an N-700 light-beam oscillograph equipped with GB-III-3 galvanometers is shown in Fig. 9.

C. VEGIK [25]

The VEGIK seismometer (see Fig. 11), designed primarily for galvanometric recording of either vertical or horizontal components of displacement with amplitudes between a fraction of a micron and 2 mm in the period range 0.01 to 1 sec, was developed in the early 1950s. It is an electromagnetic, moving-coil, pendulum seismometer with electromagnetic damping. Developed originally as a blast seismometer it has found wide application in seismology. A system consisting of VEGIK seismometers and a photographic recorder can be used to register velocities rather than displacements by simply replacing the overdamped galvanometers with high-frequency galvanometers. The period of VEGIK is adjustable between 0.8 and 1.5 sec. A helical spring in the vertical seismometer used to compensate the force of gravity is also used to adjust its period. A pendulum-positioning knob and a period-control knob are used when the VEGIK is responding to

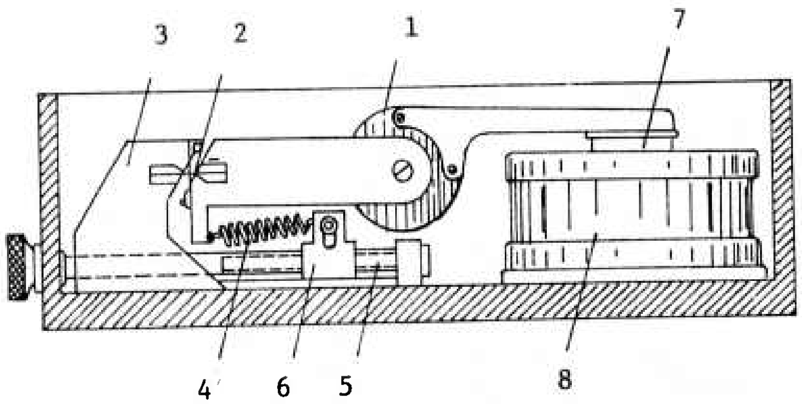

Fig. 11 -- Schematic drawing of the VEGIK seismometer [25]
1 - pendulum
2 - axis of rotation formed by two pairs of crossed steel hinges
3 - mast
4 - helical spring
5 - pendulum positioning screw
6 - period control screw
7 - coil
8 - permanent magnet

horizontal motion. The seismometer is intended for operation under stationary or field conditions, at temperatures between -20°C and +40°C and a relative humidity of up to 90 percent. The technical specifications of the VEGIK seismometer are as follows:

Natural period	1 sec (nominal)
Reduced length	0.097 m
Signal- and damping-coil sensitivities	20 V/(m/sec)
Signal- and damping-coil resistances	45 ohms
Moment of inertia	0.01 $kg \cdot m^2$
Dimensions	11 x 16 x 34 cm
Weight	10 kg

D. SM-2M [6,26]

The SM-2M (see Fig. 12), an electromagnetic, moving-coil, pendulum seismometer with electromagnetic damping is an improved version of the well-known VEGIK seismometer. It is intended primarily for galvanometric

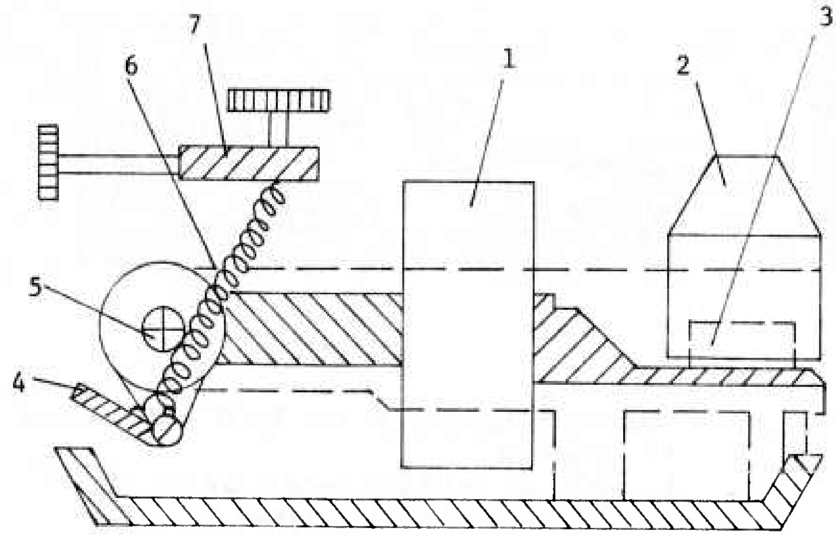

Fig. 12 -- Schematic drawing of the SM-2M seismometer [6]
1 - pendulum
2 - permanent magnet
3 - coil
4 - temperature-compensation device
5 - replaceable crossed flat hinges forming the axis of rotation
6 - helical spring
7 - spring- and period-adjustment mechanism

recording of either vertical or horizontal components of displacement with amplitudes between 0.1 μm and 3 mm in the frequency range 0.7 to 200 Hz. The SM-2M is equipped with a helical spring which compensates the force of gravity in the vertical seismometer and provides an adjustable astatizing force in the horizontal seismometer. A system consisting of SM-2M seismometers and a light-beam oscillograph can also be used to record velocities rather than displacements by replacing the overdamped galvanometers with high-frequency galvanometers.

The SM-2M can be changed from a horizontal to a vertical seismometer by rotating the seismometer assembly 90° around the horizontal axis and adjusting the helical spring. The SM-2M can be rigidly attached to an object and operated at any angle between 0 and 180° to the horizontal. It is equipped with a temperature-compensation device

which maintains the equilibrium position of the pendulum when temperature varies ±20°C from the nominal value. The natural period of the SM-2M is adjustable between 0.7 and 2 sec. It is hermetically sealed and is watertight up to 1.5 m of water. The technical specifications of the SM-2M are as follows:

Natural period	1.5 sec (nominal)
Damping factor	0.6
Reduced length	0.087 m
Signal coil sensitivity	37 V/(m/sec)
Damping coil sensitivity	12 V/(m/sec)
Signal coil resistance	130 ohms
Damping coil resistance	45 ohms
Moment of inertia	0.0085 kg·m^2
Dimensions	14.5 x 16.7 x 23 cm
Weight	5.6 kg

When first developed, the SM-2M had a single coil. This was a low-impedance coil when the SM-2M was coupled with overdamped galvanometers for use primarily in engineering work and a high-impedance coil when the seismometer was coupled to an amplifier. Damping could be introduced by shunting the coil by means of an external switch. Characteristics of the older SM-2M seismometer, with a low-impedance coil, which differ from those of the SM-2M described above are:

With low-impedance coil

Coil resistance	140 ohms
Shunt resistance	150 ohms
Electromagnetic damping factor	0.5
Equivalent resistance	72 ohms
Signal coil sensitivity with the shunt connected	20 V/(m/sec)

E. SM-3 [6]

The SM-3 (see Fig. 13), an electromagnetic, moving-coil, pendulum seismometer with electromagnetic damping is an improved version of the SM-2M. Minor design changes slightly improved its response to large amplitude displacements (from 3 mm for SM-2M to 5 mm for SM-3) and extended the lower limit of its frequency range (from 0.7 Hz for SM-2M to 0.5 Hz for SM-3). However, the major improvement of the SM-3 over the SM-2M is the convenience and the ease of its operation. The natural period of the SM-3 is adjustable between 0.7 and 3 sec. The technical specifications of the SM-3 are as follows:

Natural period	2 sec (nominal)
Damping factor	0.6
Reduced length	0.085 m
Signal- and damping-coil sensitivities	20 V/(m/sec)
Signal- and damping-coil resistances	65 ohms
Moment of inertia	0.0089 $kg \cdot m^2$
Weight	5.5 kg

In all other respects the SM-3 seismometer appears to be identical to the SM-2M.

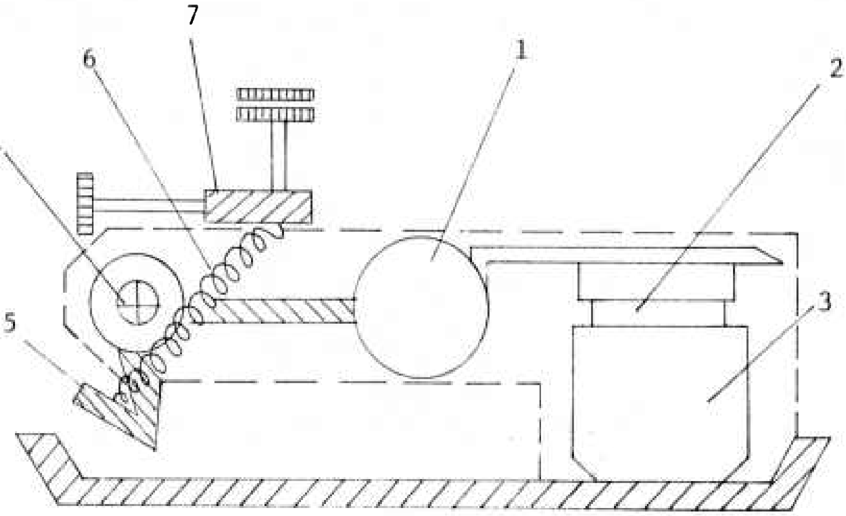

Fig. 13 -- Schematic drawing of the SM-3 [6]
1 - pendulum
2 - coil
3 - permanent magnet
4 - crossed flat hinges forming the axis of rotation
5 - temperature-compensation device
6 - helical spring
7 - spring- and period-adjustment mechanism

F. S5S [6,27,28]

The S5S (Fig. 14) is an electromagnetic, moving-magnet, double-pendulum seismometer with adjustable electromagnetic damping intended primarily for galvanometric recording of either vertical or horizontal components of displacement with amplitudes between 0.01 μm and 15 mm in the period range 0.01 to 5 sec. A system consisting of S5S seismometers and oscillographs can also record velocities rather than displacements by replacing the overdamped galvanometers with high-frequency galvanometers. The S5S can be changed from a horizontal to a vertical seismometer by rotating the seismometer assembly 90° around the horizontal axis and adjusting the spring. The pendulum of the seismometer consists of two rigidly connected cylindrical magnets located on opposite sides of the axis of rotation. The pendulum is suspended from the stand by two pairs of crossed, flat hinges forming the axis

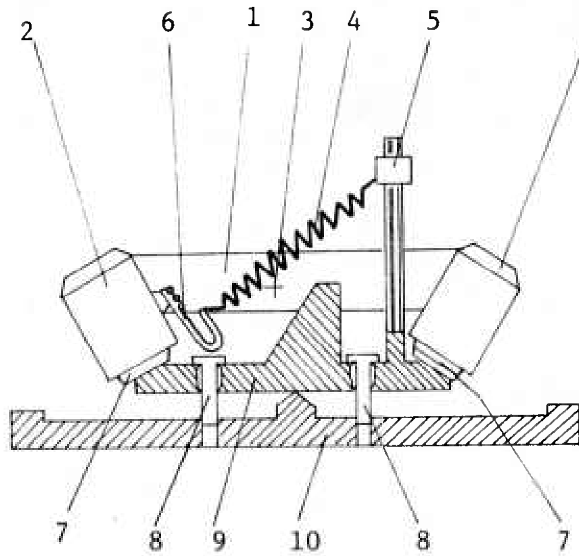

Fig. 14 -- Schematic drawing of the S5S seismometer [6]
1 - pendulum
2 - magnet
3 - axis of rotation of the pendulum
4 - zero-length spring
5 - control of the equilibrium position
6 - temperature-compensation device
7 - signal and damping coils
8 - period-adjustment screw
9 - base of the stand
10 - base of the frame

of rotation. A helical spring between the mast and the temperature-compensation device, located on the side of one of the magnets, balances the weight of the pendulum. The seismometer is equipped with two stationary coils (signal and damping) attached to the stand. Its natural period can be adjusted between 1 and 5 sec by changing the angle between the stand and the base of the frame. It is hermetically sealed and can operate at temperatures between -50°C and +50°C. The principal parameters of the S5S are as follows:

Natural period	5 sec (nominal)
Reduced length	0.425 m
Signal-coil sensitivity	12.8 V/(m/sec)
Damping-coil sensitivity	6.3 V/(m/sec)
Coil-resistance (both coils)	88 ohms
Moment of inertia	0.066 kg·m^2
Dimensions	15 x 16 x 36 cm
Weight	11 kg

The technical specifications of a strong-motion system consisting of an S5S seismometer and an ISO-2M recording unit responding to displacements and velocities are given in Table 3. The frequency response of these systems operating at many Soviet stations are shown in Figs. 15 and 16.

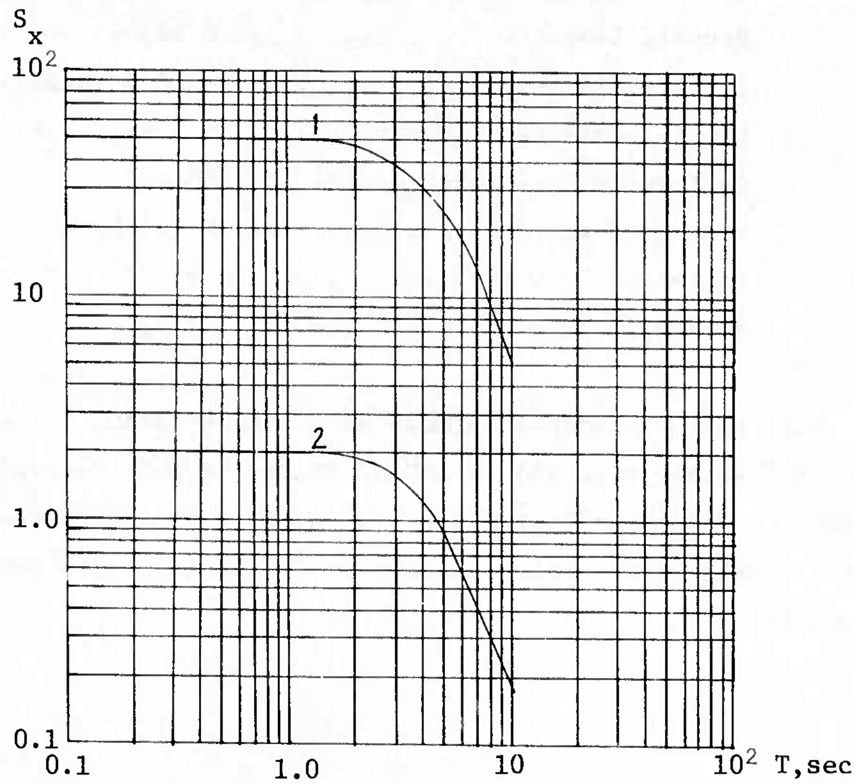

Fig. 15 -- Magnification curves of a strong-motion displacement seismograph consisting of an S5S seismometer and an ISO-2M recording unit with GB-IV-C-3 galvanometers with the following constants [29]:

$T_s = 5$ sec

$D_s = 0.7$

$T_g = 0.17$ sec

$D_g = 12$

$\sigma^2 << 0.01$

$\bar{v} = v_{max} = 50$ (curve 1) and 2 (curve 2)

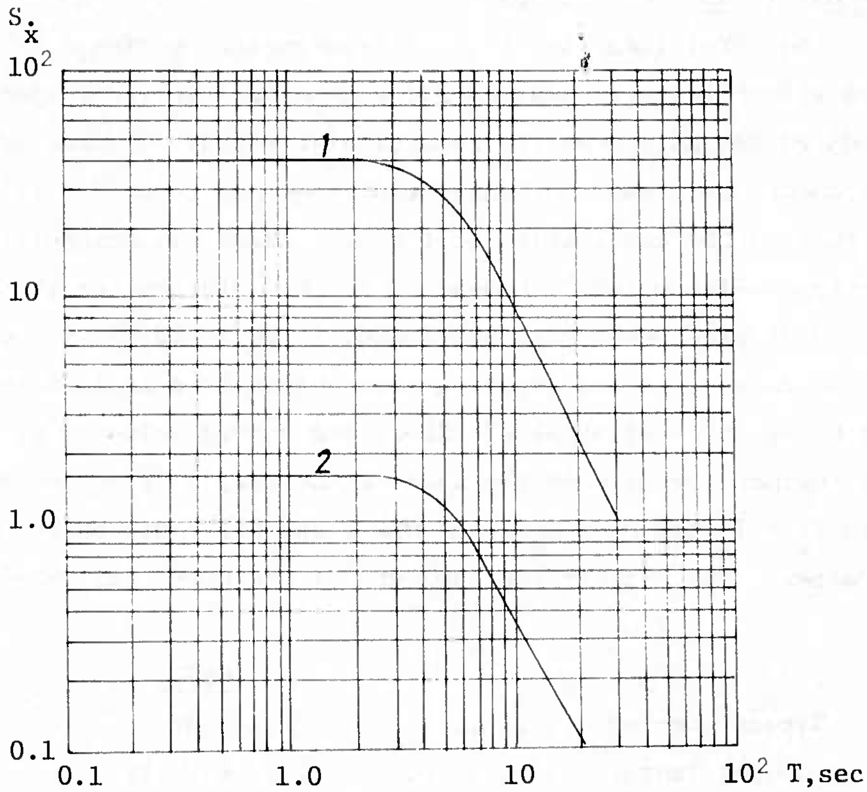

Fig. 16 -- Velocity sensitivity curves of a strong-motion velocity seismograph consisting of an S5S seismometer and an ISO-2M recording unit with GB-IV-S-10 galvanometers with the following constants [29]:

T_s = 5 sec

D_s = 0.7

T_g = 0.08 sec

D_g = 0.7

$S_{\dot{x}}$ = 40 mm/(cm/sec) (curve 1)

$S_{\dot{x}}$ = 1.6 mm/(cm/sec) (curve 2)

G. OSP-1 AND OSP-2 [6,30]

The OSP-1 (see Fig. 17) electromagnetic, moving-coil seismometer with electromagnetic damping and a translating-type suspension is intended for galvanometric recording of either vertical or horizontal components of ground motion in the frequency range 0.7 to 35 Hz. (OSPG-1 is the designation of the horizontal seismometer, OSPV-1 of the vertical seismometer.) Depending on the galvanometer the OSP-1 can record displacements with amplitudes 10 μm to 10 cm, velocity of up to 150 cm/sec, or acceleration with unspecified maximum amplitude. The OSP-2, a later model of OSP-1, can record velocity of up to 350 cm/sec. The seismometer is commonly used in inverted seismograph systems, i.e., with $T_s > T_g$ and $D_s < D_g$. The OSP-1 and OSP-2 are watertight to 1 m of water. The principal parameters of the OSP-1 and OSP-2 are as follows:

	OSP-1	OSP-2
Natural period	5 Hz	6.3 Hz
Damping factor	6 to 11	15
Signal-coil generator constant	15 V/(m/sec)	11 V/(m/sec)
Damping-coil generator constant	5.5 V/(m/sec)	--
Signal-coil resistance	11 ohms	--
Damping-coil resistance	4 ohms	--
Inertial mass	40 gm	--
Base diameter	9.4 cm	--
Height	13.7 cm	--
Weight	4.6 kg	--

The small size and rugged construction (they can withstand impact of up to 20 g) make the OSP-1 and OSP-2 convenient for borehole use. The specifications of a strong-motion system consisting of an OSP seismometer and an ISO-2M recording unit are given in Table 3.

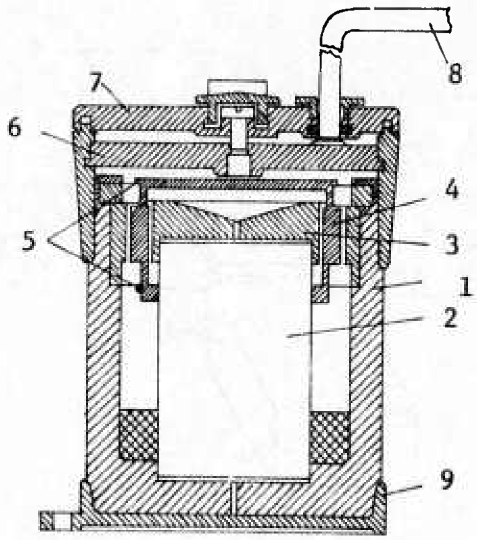

Fig. 17 -- Schematic drawing of the OSP-1 seismometer [6]
1 - housing forming magnetic shunt
2 - cylindrical magnet
3 - pole piece
4 - signal and damping coils
5 - flat hinge
6 - clamp
7 - cover
8 - cable
9 - base plate

H. TORSION SEISMOMETER [31 to 33]

Figure 18 is a schematic drawing of a strong-motion torsion seismometer. It consists of a multiturn coil (similar to the coils used in the GB-III and GB-IV galvanometers) suspended in the air gap of a permanent magnet, and a mirror attached to one of the suspensions. The suspension-and-coil assembly of the seismometer is unbalanced, i.e., the axis of rotation does not pass through the center of mass. This is achieved by one of the three methods illustrated in Fig. 19. The simplest method (see Fig. 19a) is to displace the mirror that is attached to one of the two suspensions. By a second method (see Fig. 19b) the points of contact of suspensions with the coils are displaced relative to the symmetry axis of the coil. Fine control of the desired degree of unbalance is obtained in these two methods by adding a thin wire with

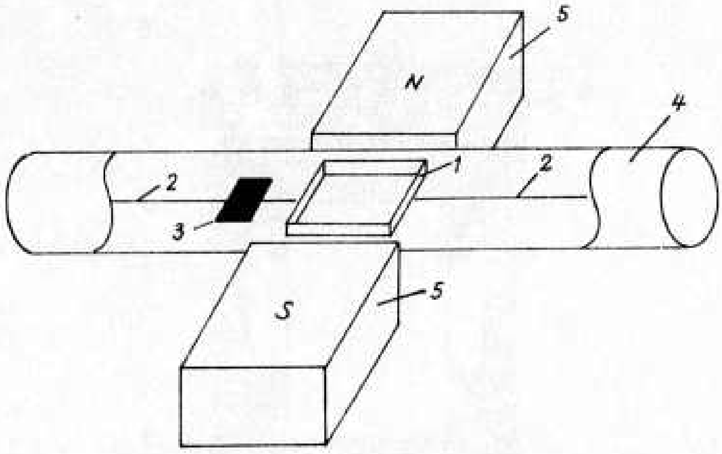

Fig. 18 -- Schematic diagram of the torsion seismometer [31]
1 - coil
2 - suspension
3 - mirror
4 - housing
5 - permanent magnet

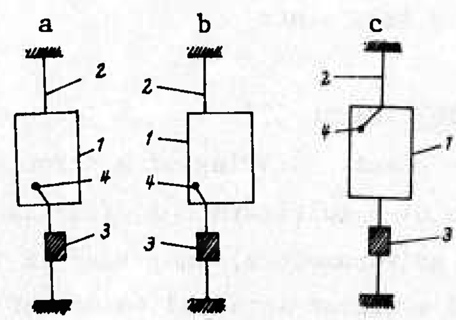

Fig. 19 -- Different methods of unbalancing the suspension and coil assembly of the torsion seismometer [32]
a - displacement of the mirror
b - displacement of the points of contact between the suspensions and the coil
c - introduction of a fused globule

a fused globule at its end. The third method (see Fig. 19c) is to use this fused globule technique by itself. The seismometer is damped by adding external resistance across the coil circuit.

I. AP-2M [34]

The AP-2M piezoelectric accelerometer (see Fig. 20) is intended for registration of either vertical or horizontal components of acceleration of up to 1.5 g. The latest version of the AP-2 model [35], it has been modified by incorporating an insulated-gate field-effect transistor (IGFET) in the preamplifier circuit, rearranging the piezoelectric plates, and enclosing the preamplifier within the accelerometer. The resonant frequency of the AP-2M is 2 kHz, and its sensitivity is 1 to 7 V/g. The AP-2M accelerometer consists primarily of the inertial mass (3) and two piezoelectric plates (4) enclosed in one of the chambers (2). The other chamber houses a preamplifier, batteries sufficient for up to 900 hours of continuous operation, and other electrical components. The acceleration sensitivity curve of a system consisting of three AP-2M accelerometers and an ISO-2 recording unit is shown in Fig. 21.

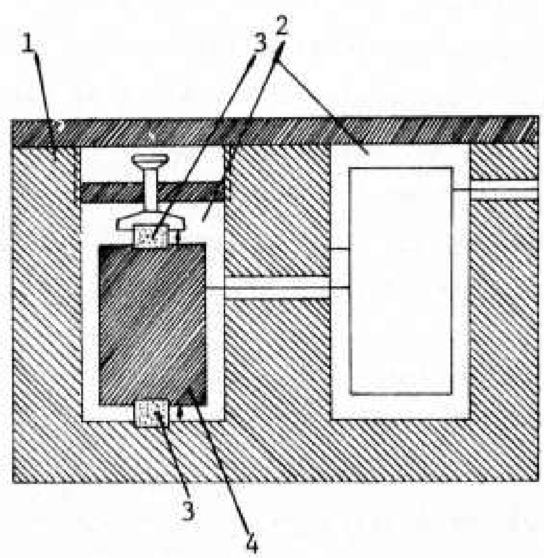

Fig. 20 -- Schematic diagram of the AP-2M accelerometer [34]
1 - housing
2 - chamber
3 - piezoelectric plate (arrow indicates the direction of polarization)
4 - inertial mass

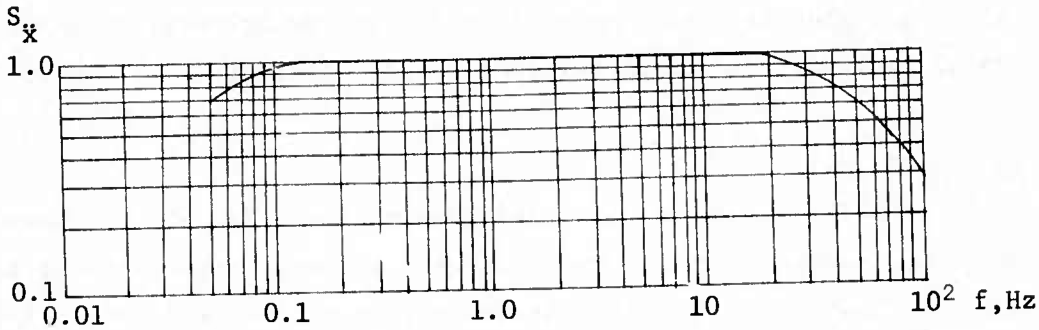

Fig. 21 -- Acceleration sensitivity curve of an accelerograph system consisting of three AP-2M accelerometers coupled to six GB-IV-B-2 galvanometers, used in the ISO-2 recording unit. The galvanometer frequency is 60 Hz [34]

The AP-2M piezoelectric accelerometer was used in a digitally recording, three-component, strong-motion system operating in a standby mode. The accelerometer was coupled to an analog-to-digital converter, UZU magnetic-tape loop with an eight-second memory, a seismic triggering unit, and an exploration-type magnetic tape recorder. Below a certain threshold the signals from the accelerometers are digitized, recorded on the tape loop, and erased by a magnet. Any signal above the threshold activates the power supply to the amplifier and to the tape recorder, which then registers an event in binary code without the loss of first motion. The analog-to-digital converter is a 10-channel, 11-bit successive-approximation unit with a sampling rate of 100 samples per second. Time marks are recorded every 20 seconds. The available technical specifications of the system are as follows [36]:

Resonant frequency	2 kHz
Accelerometer sensitivity	6.57 V/g
Frequency range	0.5 to 40 Hz
Recordable accelerations	1.5 to 1500 gal
Dynamic range	60 dB
Tape loop	
width	3.2 cm
speed (loop and tape recorder)	40 cm/sec
Power supply	
for tape loop	12 V
for overall system (standby mode)	15 W
(activated mode)	75 W

J. APT-1 [37.38]

The APT-1 (see Fig. 22) is a piezoelectric, three-component strong-motion and blast accelerometer developed for registration of earthquakes of intensity II to XII and the response of structures to impulsive or oscillatory loads, where the upper limit of measurable accelerations does not exceed 2 g. The accelerometer is intended to be coupled to electronic amplifiers and tape recorders. However, it is presently being used for galvanometric registration of strong motion at frequencies $f \geq 0.15$ Hz, with the recording capability at higher frequencies being limited only by the galvanometers used in the oscillograph. The inertial mass of the APT-1 (Fig. 22, 1) consists of a brass cube 7.5 cm on a side, weighing about 1.5 kg, with zirconate-lead titanate plates (pressure sensors) (2) 0.2 cm thick and 2.5 cm in diameter glued to the center of each side of the cube. The capacitance of each of the piezoelectric plates is about 3000 pF.

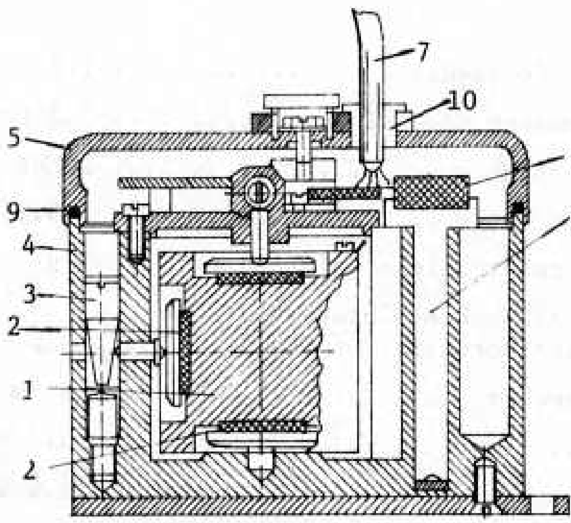

Fig. 22 -- Schematic diagram of the APT-1 accelerometer [38]
1 - inertial mass
2 - zirconate-lead titanate plate
3 - wedge-shaped clamp
4 - housing
5 - cover
6 - amplifier
7 - cable
8 - power supply (battery)
9 - rubber gasket

The six plates and the inertial mass are fixed within the cylindrical housing (4) by means of five wedge-shaped clamps (3) which control the pressure exerted by the plates. Varying the pressure by inserting or withdrawing the clamps makes it possible to adjust the natural frequency of each sensor by as much as ±10 percent from the nominal value of 1.5 kHz. One face of each of the six sensor plates is electrically connected with the inertial mass and the housing while the other faces are electrically interconnected. The leads from each pair of sensor plates are connected to a three-channel IGFET (insulated-gate field-effect transistor) preamplifier (6) with a one Gohm impedance. The internal power supply (8), two mercury oxide power cells rated at 2.8 A-hours, is sufficient to operate the APT-1 for up to six months unattended. The accelerometer is intended for operation under stationary and expeditionary conditions at temperatures between -20°C and +40°C and relative humidity of up to 100 percent. The specifications of the APT-1 accelerometer are as follows:

Resonant frequency	1.5 kHz
Accelerometer sensitivity	0.3 to 0.5 V/g
Dynamic range	80 dB
Frequency range	≥ 0.15 Hz
Maximum recordable acceleration	2 g
Maximum allowable vibrational and impact acceleration	10 g
Base diameter	13 cm
Height	15.4 cm
Weight	14.6 kg
Power requirements	12 to 15 V, 1 mA

The technical specifications of a strong-motion system consisting of an APT-1 accelerometer and an ISO-2M recording unit are given in Table 3, and the acceleration sensitivity curve of a system consisting of an APT-1 accelerometer and an ISO-2M light-beam oscillograph equipped with GB-IV-B-2 galvanometers is shown in Fig. 23.

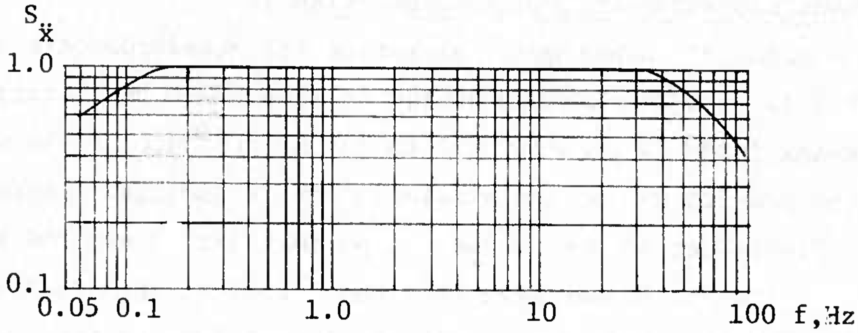

Fig. 23 -- Acceleration sensitivity curve of a strong-motion system consisting of an APT-1 seismometer coupled to GB-IV-B-2 galvanometers used in the ISO-2M recording unit. The galvanometer frequency f_g = 60 sec and the sensitivity of the system is 7 mm/g [38]

An improved piezoelectric accelerometer with lower sensitivity to parasitic modes was recently described in [39]. In this model (see Fig. 24), the inertial mass is a sphere centered by means of a subassembly, which consists of three pairs of planoconcave centering elements located between the sphere and the piezoelectric sensors, rods, and springs. The concave side of the centering elements is in contact with the inertial mass and the flat side is attached to the piezoelectric sensors.

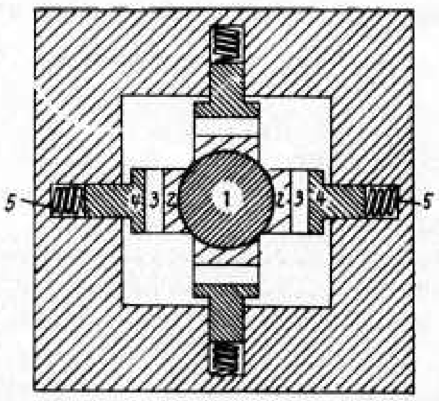

Fig. 24 -- Schematic drawing of the modified model of the piezoelectric accelerometer [39]
1 - inertial mass
2 - inertial mass centering element
3 - piezoelectric sensor
4 - rod
5 - spring

K. PARAMETRIC PIEZOELECTRIC ACCELEROMETER [40,41]

The major disadvantage of piezoelectric accelerometers such as the APT-1 is that the maximum period of recordable accelerations at constant sensitivity is proportional to the capacitance of the sensor, while the sensitivity of the accelerometer is inversely proportional to it. Piezoelectric accelerometers parametrically excited at their resonant frequency do not have this basic limitation. In theory, such instruments should respond at the lowest frequencies, down to dc, without a decrease in their sensitivity.

This principle was utilized in constructing a strong-motion piezoelectric accelerometer consisting of a piezoelectric sensor loaded by an inertial mass resonantly excited by a generator connected to the sensor through an isolating network. Vibrations of the inertial mass induced by seismic processes modulate the resonant vibrations of the piezoelectric sensor. The amplitude of the modulated signal from the sensor is given by the following expression:

$$A = k\left(\frac{1}{1 + p}\right), \tag{1}$$

where k is a constant and p is the load.

The technical specifications of an experimental parametric piezoelectric strong-motion accelerometer developed at the Institute of Physics of the Earth in the early 1970s are as follows:

Piezoelectric sensor	
Resonant frequency	96 kHz
Capacitance	3000 pF
Load resistance	2 kohms
Dimensions	25 mm diameter
Inertial mass	3.2 kg
Generator	
Voltage output	30 V
Output resistance	5 kohms
Mean accelerometer sensitivity to acceleration between -0.5 and +0.5 g	0.1 V/g

The unsymmetrical form of formula (1) in respect to the zero position of the inertial mass makes processing seismic data acquired by the type of sensor described above difficult, and measuring negative accelerations during unloading in excess of 1 g impossible. This difficulty can be avoided by locating two identical, parametrically excited piezoelectric sensors on the opposite sides of the inertial mass. In this arrangement, the inertial mass exerts a force or pressure of equal magnitude but of opposite sign on the two piezoelectric cells. Depending on polarization of the sensors, the two output signals are either added or subtracted. In the latter case, the amplitude of the modulated output from both sensors is given by the following formula:

$$A = \frac{2\ kp}{1-p^2}\ , \qquad (2)$$

and is independent of the direction in which the force or the pressure exerted by the inertial mass on the sensors is directed. In the limiting case of small accelerations of the medium acting on the load, the amplitude is directly proportional to the load, i.e., $A = 2\ kp$.

L. SMRO MECHANICALLY RECORDING HORIZONTAL-COMPONENT STRONG-MOTION SYSTEM [6]

The SMRO strong-motion system (see Fig. 25) consists of two pendulum-type, horizontal-component seismographs with electromagnetic damping, recording on smoked or heat-sensitive paper. It is intended for direct mechanical recording of horizontal components of displacement with amplitudes up to 10 to 20 cm generated by very strong or catastrophic earthquakes. The SMRO is used primarily in the UBOPE-O system for rapid determination of epicenters of possible tsunami-generating earthquakes. In this seismograph, recording is along a straight line without translation of the drum. The period of the SMRO is adjustable between 2 and 8 sec. The spring-loaded drive makes it possible to record continuously for 6 to 12 hours without rewinding the spring. The SMRO is intended for operation under stationary conditions at temperatures between -30°C

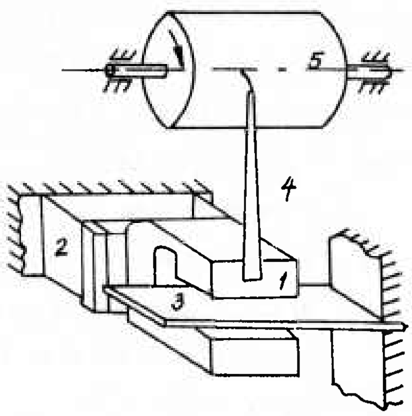

Fig. 25 -- Schematic drawing of the SMRO seismograph [6]
1 - magnet and seismic mass
2 - suspension
3 - damping plate
4 - pen
5 - recording drum

and +30°C and a relative humidity of up to 95 percent. The technical specifications of the SMRO are as follows:

Natural period	4 sec (nominal)
Damping factor	0.5
Magnification	1
Recording medium	Smoked or heat-sensitive paper
Recording speed	30 to 60 mm/min ±30%
Record duration	12 hrs at 30 mm/min and 6 hrs at 60 mm/min
Power supply with heated stylus	2 V, 0.8 A
Dimensions	50 x 40 x 30 cm
Weight	20 kg

According to [2] the basic disadvantages of the SMRO are its uneven recording speed, the considerable thickness of the trace, and a narrow passband.

M. SMTR* MECHANICALLY RECORDING, HORIZONTAL-COMPONENT STRONG-MOTION SYSTEM [6,42]

The SMTR strong-motion system (see Fig. 26) consists of two pendulum-type, horizontal-component displacement seismographs equipped with an electromagnetic damping plate, recording on smoked or heat-sensitive paper. It is intended for direct mechanical recording of horizontal components of displacement with amplitudes up to 5 cm in the period range 0.05 to 3 sec. The pendulum of the SMTR is an 8-kg brass cylinder attached to two stands by four 0.15 to 0.2 mm thick flat hinges crossed in pairs. The recording unit consists of a drum and a spring-loaded drive. Translation of the drum makes it possible to record continuously for up to 75 hours. The seismograph is intended for operation at permanent stations at temperatures between -30°C and +30°C and a relative humidity of up to 95 percent. The technical specifications of the SMTR are as follows:

Natural period	5 sec
Damping factor	0.4 to 0.5
Reduced length	10 cm
Magnification	7.5
Recording medium	Smoked or heat-sensitive paper
Recording speed	60 mm/sec ±30%
Recording duration	Up to 75 hrs
Timing marks	1 ppm
Dimensions	80 x 40 x 35 cm
Weight	40 kg

A standard magnification curve of an SMTR system is shown in Fig. 27. According to [2], the basic disadvantage of the SMTR is its low and uneven recording speed.

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*Also referred to as the SMR-2 or SMR-2M.

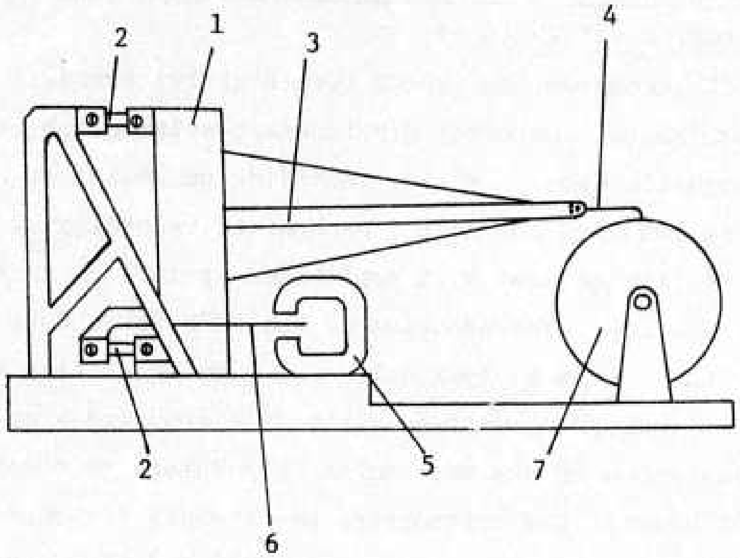

Fig. 26 -- Schematic drawing of the SMTR seismograph [6]
1 - pendulum
2 - flat hinges
3 - lever
4 - stylus
5 - damping magnet
6 - damping plate
7 - recording drum

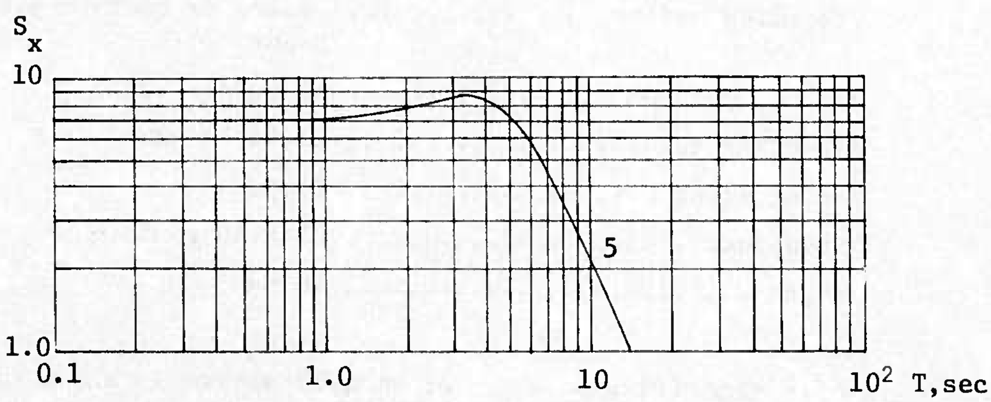

Fig. 27 -- Magnification curve of an SMTR seismograph with the following instrumental constants:

$T_s = 5$ sec

$D_s = 0.456$

N. UAR-M STANDBY THREE-COMPONENT ACCELEROGRAPH SYSTEM FOR UNATTENDED OPERATION [43 to 45]

The UAR-M (see Fig. 28), an optically recording three-component strong-motion accelerograph system developed for registration of ground or structural accelerations between 30 and 500 cm/sec^2 (seismic events of intensity I = VI to X), is designed for unattended operation for up to one year. The UAR-M is started by a seismoscope triggered by the first impulse, with the loss of motion claimed not to exceed 0.1 sec.

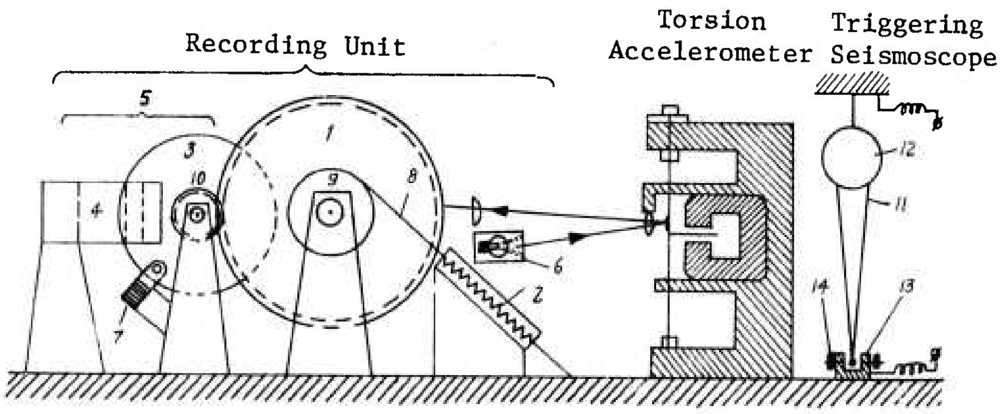

Fig. 28 -- Schematic drawing of the UAR-M accelerograph system [45]

1 - aluminum recording drum
2 - helical spring
3 - aluminum disc
4 - permanent magnet
5 - damper
6 - lamp
7 - brake
8 - twine
9 - small drum
10 - gear
11 - duraluminum arm
12 - cylindrical mass of pendulum
13 - brass cylinder
14 - carbon-tipped screw

The system is compact, with three torsion accelerometers mounted on the same frame as the recording unit, the triggering seismoscope, and a power supply. In the standby mode, the helical spring (2) is under tension but is prevented from turning the recording drum (1) by a special brake (7).

Each of the two horizontal accelerometers in the UAR-M consists of a thin, horizontally-oriented aluminum disc (3) located in the air gap of the permanent magnet (4). The aluminum disc is attached to a taut vertical wire forming the axis of rotation. In the vertical accelerometer the taut wire is oriented horizontally. The accelerometers can be replaced by lower frequency torsion seismometers; this makes it possible

to record the three components of displacement, or with heavy damping, the three components of velocity.

The recording unit consists of an aluminum drum (1), helical spring (2) for turning the drum, a damper (5) to ensure a uniform rotation rate of the drum, a lamp (6), and a brake (7). The aluminum drum is mounted on a steel axle which rotates in ball bearings emplaced in two stands attached to the base of the frame. A length of thin twine (8) is wound on a small drum (9) mounted on the same axle. The free end of the twine is tied to the helical spring (2). The other end of the spring is fastened to a stand. The helical spring is enclosed in a metal tube to eliminate transverse vibrations.

The damper consists of a light aluminum disc (3) mounted in the same manner as the drum (1). Part of the disc is located in the gap of the permanent magnet (4). The rim of the drum is serrated and is coupled to the aluminum disc through an intermediate gear wheel (10) mounted on the same axle as the disc. The gear ratio is such that the angular velocity of the disc is ten times that of the drum. Rotation of the drum (1) and the disc (3) induces eddy currents in the disc which interact with the magnetic field of the magnet (4); this exerts a braking action and thus ensures a uniform rotation rate of the drum.

The triggering seismoscope, an inverted pendulum with two horizontal degrees of freedom, is suspended from a steel wire. A duraluminum arm (11) is fastened to the cylindrical mass (12) of the pendulum. At the lower end of the arm, a carbon rod forming one of the electrical contacts fits into the hollow center part of a small brass cylinder (13) mounted on the base of the frame. Four adjustable, carbon-tipped screws (14) penetrate the wall of the hollow brass cylinder. The sensitivity of the triggering seismoscope depends on the gap between the carbon rod on the duraluminum arm and the carbon contacts on the tips of the four adjustable screws.

The recording of an event stops automatically after the 30 sec required for one-half revolution of the drum; the drum velocity is claimed to be sufficiently uniform so as not to require time marks. The UAR-M can record two events. The system is intended for operation under stationary or field conditions at temperatures between -30°C and +30°C and a relative humidity of up to 90 percent.

The technical specifications of the UAR-M are as follows:

Natural frequency	25 Hz
Damping factor	0.6
Acceleration sensitivity	14 mm/g
Reduced length	1.9 cm
Optical lever	27.2 cm
Recording speed	1.0 cm/sec
Film width	60 mm
Length of film	60 cm
Power supply	2 sources: 6 V and 100 V dc
Dimensions	76 x 34 x 35 cm
Weight	50 kg

The UAR has a number of deficiencies, including an unreliable seismoscope trigger, insufficiently sensitive accelerometers, a recording capability limited to only two earthquakes, and the absence of time marks [46].

An acceleration sensitivity curve of the UAR-M accelerograph is shown in Fig. 29.

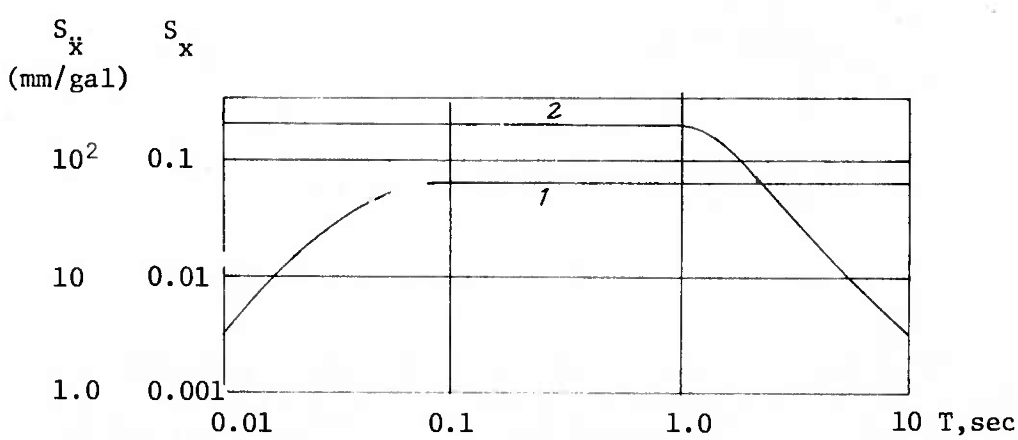

Fig. 29 -- Acceleration sensitivity of the UAR-M accelerograph system (curve 1) and displacement sensitivity of the ESS-1 seismograph system (curve 2) [21; the ESS-5, a new model of the ESS-1, is described on pp. 59-63.

O. SSRZ STANDBY THREE-COMPONENT SYSTEM FOR UNATTENDED OPERATION [47,48,6]

The SSRZ is a portable, three-component, strong-motion system for direct optical recording of accelerations of the ground or man-made structures in seismic areas of intensity VI to IX or of velocity in areas of intensity IV to VII. Operating in the standby mode the system consists of three pendulum seismometers with liquid or electromagnetic damping. The SSRZ is started by a vertical seismometer with an electronic amplifier triggered by the first impulse, with the loss of motion between 0.05 to 0.1 sec. A schematic drawing of the latest model of the SSRZ system is shown in Fig. 30, and its velocity and acceleration sensitivity curves

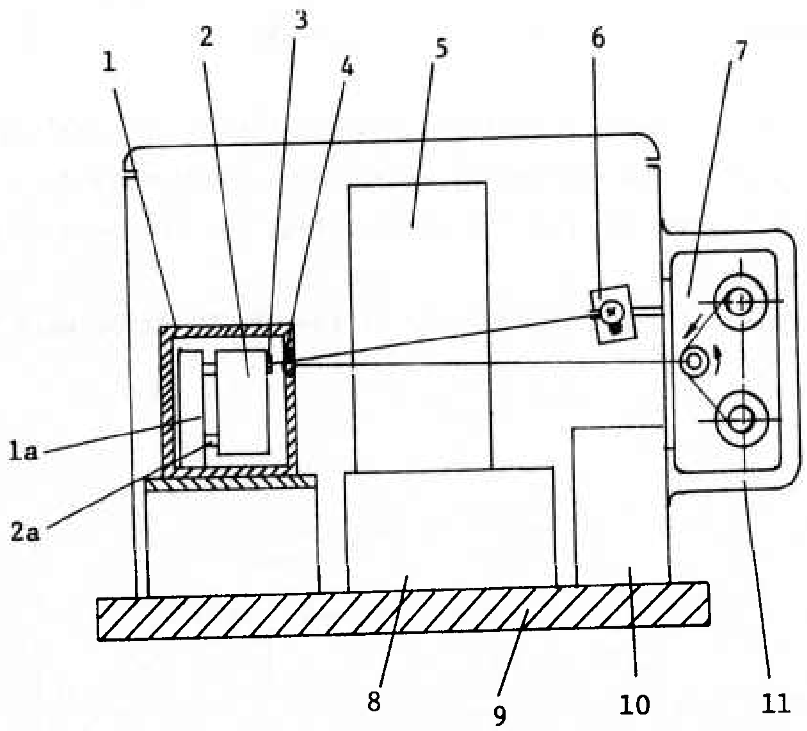

Fig. 30 -- Schematic drawing of the SSRZ seismograph [6]
1 - accelerometer
2 - inertial mass
3 - mirror
4 - lens
5 - starter
6 - lamp and pinhole
7 - cassette
8 - electrical components
9 - frame
10 - dc electrical motor
11 - cassette enclosure

are plotted in Fig. 31. In the SSRZ with liquid damping, the accelerometer (1) consisting of an inertial mass (2) attached to stand (1a) by the two thin steel hinges (2a), is immersed in a fluid. (In the SSRZ with electromagnetic damping, a cylindrical copper coilformer and the coil are supported in the cylindrical gap of a permanent magnet by two pairs of crossed hinges.) The motion of the inertial mass is recorded on 35-mm photographic film in cassette (7). The optical system consists of a source of light and a pinhole (6), a mirror (3) attached to the inertial mass, and a lens (4). The film is driven by a dc electrical motor with a gear train (10). One-half second time marks and the temperature are recorded on the film. The power supply consists of dry cells or 12-V storage cells located outside the main unit. The starter (5) is triggered by an electromagnetic vertical seismometer with $f_s = 3$ Hz when the ground velocity reaches 0.3 to 0.5 cm/sec or when acceleration exceeds 10 cm/sec^2.

Film speed of 6 mm/sec makes it possible to record ten events of 60 sec duration each. The system is intended for operation under stationary or field conditions and can operate at temperatures between -10°C and +40°C and a relative humidity of up to 95 percent. The technical specifications of the SSRZ accelerograph with liquid damping at a temperature of 10°C are as follows:

Natural frequency	30 or 35 to 40 Hz
Frequency range	0 to 15 Hz
Damping factor	0.6
Acceleration sensitivity	45 to 50 or 12 mm/g
Dynamic range	40 dB
Film speed	3 or 6 mm/sec
Film length	3.5 m
Maximum recordable acceleration ...	3 g
Dimensions	45 x 30 x 28.5 cm
Weight	22 kg (without power supply)

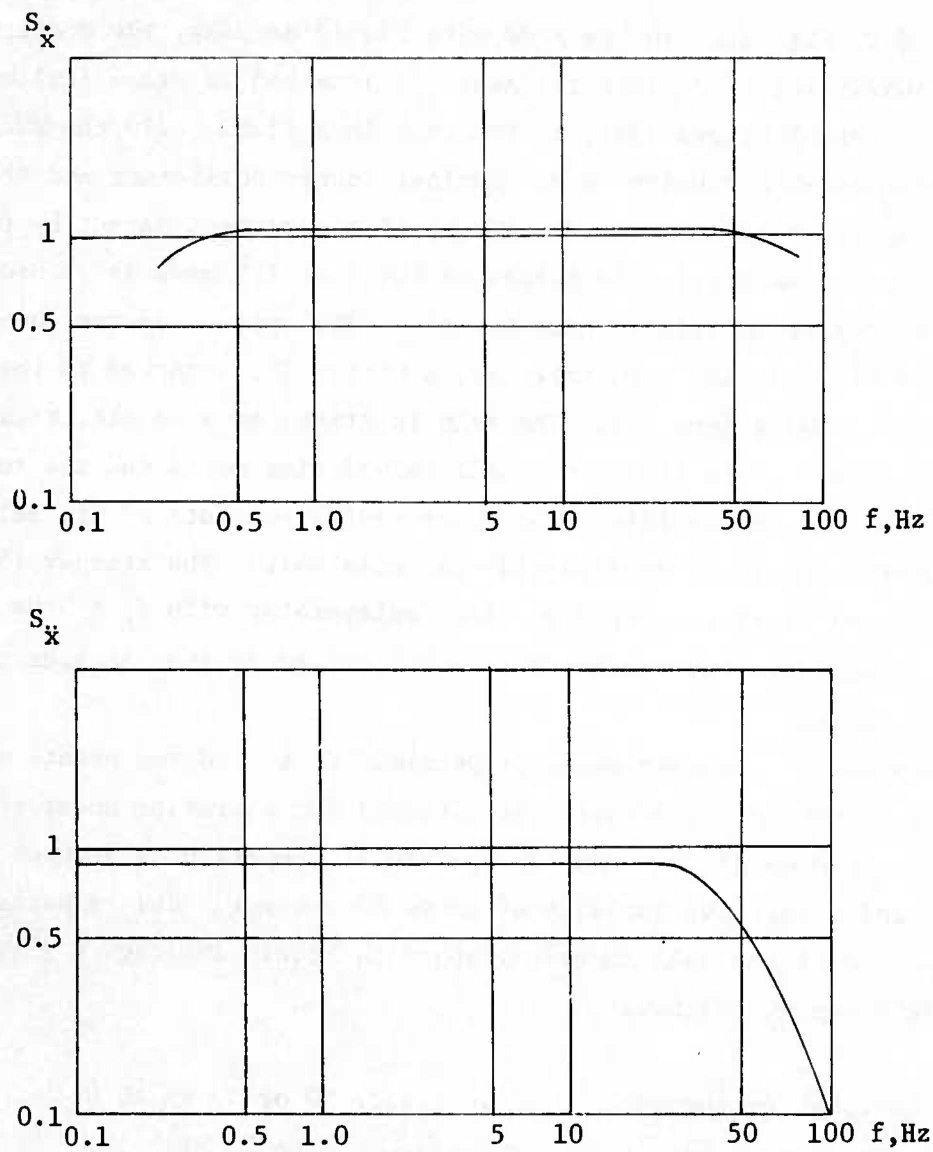

Fig. 31 -- Sensitivity curves of the SSRZ operated as a velocimeter (above) and as an accelerometer (below), with $S_{\ddot{x}}$ = 12 mm/g [48]

The natural frequency of the accelerograph with electromagnetic damping is 20 Hz, its acceleration sensitivity is 15 mm/g, and the reduced pendulum length is 2.4 cm. The other specifications are the same as for the SSRZ with liquid damping.

The SSRZ can also be used as a velocity meter by replacing the accelerometer with a seismometer that has liquid damping and the following parameters: natural frequency of 10 Hz, damping factor of 30, and velocity sensitivity of 0.24 m/(cm/sec).

P. ESS-5 CONTINUOUSLY RECORDING, THREE-COMPONENT DISPLACEMENT SEISMOGRAPH SYSTEM FOR UNATTENDED OPERATION [49,50]

The ESS-5 (see Fig. 32), a portable, three-component, strong-motion system consisting of three pendulum seismometers with electromagnetic damping, a direct microphotorecording assembly, and a power supply is designed for continuous registration of the three components of displacement for a period of up to one month. The axis of rotation of each of the three pendulums is formed by two pairs of 20-μm-thick crossed flat hinges. A horizontal helical spring connects the pendulum of the horizontal seismometer to the frame. The vertical seismometer is equipped with a zero-length spring and an automatic pendulum adjustment device. Damping is provided by thin aluminum plates attached to the pendulums and placed in the air gaps of permanent magnets.

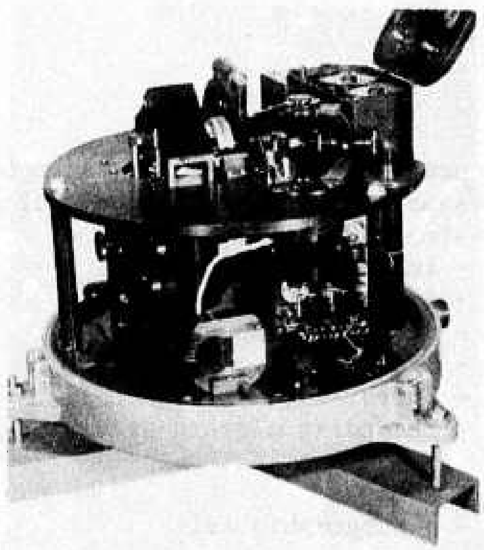

Fig. 32 -- The ESS unattended, three-component, strong-motion system [51]

The microphotorecording assembly used in the ESS-5 (see Fig. 33) consists of an incandescent bulb (1); lens (2); rectangular slit (3) at the primary focal point of lens (4); mirror-sweep subassembly (5); three recording mirrors (6) attached to the pendulums of the three seismometers; and stationary photographic film (8) at the primary focal point of lens (7). In the absence of ground motion, the three parallel beams of light (images of the slit) formed by reflection from the three mirrors of the mirror-sweep subassembly (5) are also reflected by the

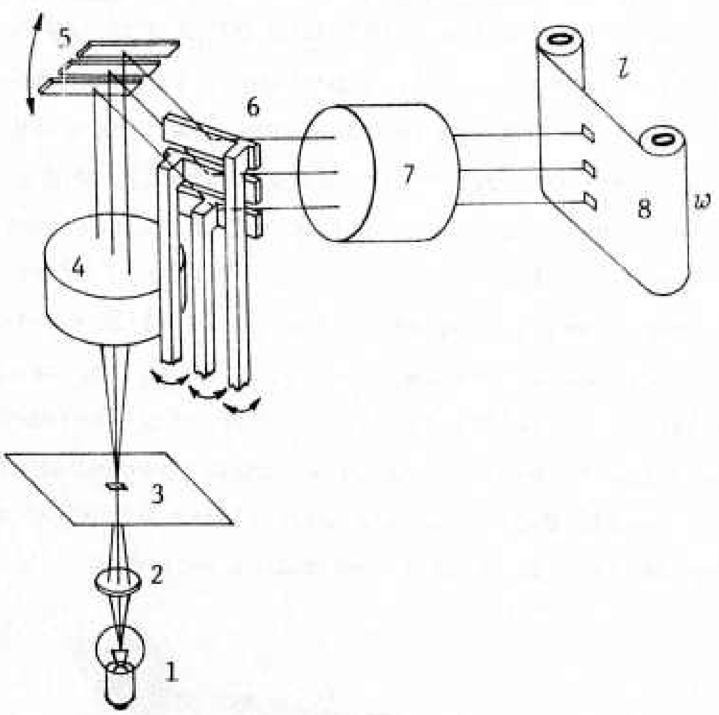

Fig. 33 -- Schematic drawing of the microphotorecording assembly used in the strong-motion ESS-5 system [49]
1 - incandescent bulb
2 - lens
3 - narrow rectangular slit
4 - lens
5 - mirror-sweep subassembly
6 - recording mirrors attached to the pendulums
7 - lens
8 - photographic film

recording mirrors (6) and focused onto film (8) by lens (7). As a result of slow rotation of the mirror-sweep assembly, the images of the rectangular slit form three straight parallel lines which are recorded along the width (w), rather than the length (l) of the stationary film. While having no effect on the constant speed of rotation of the mirror-sweep subassembly, ground motion induces to-and-fro movement of recording mirrors. Since the axes of rotation of the mirror-sweep subassembly and recording mirrors are perpendicular to each other, the three components of displacements are recorded along the length of the film and perpendicular to the straight lines recorded in the absence of ground motion. When the light beams reach the edge of the film, i.e., when the mirror-sweep subassembly rotates through a certain angle it moves rapidly backward to its initial position, simultaneously advancing the film a specified distance along its length.

The mirror-sweep subassembly is driven by a low-power dc motor of somewhat unusual design, illustrated in Fig. 34. A beam of light from the incandescent bulb used for photo-optical recording is incident sequentially on one of the three photodiodes which activate a switch connecting the battery to the motor. A surge of current through one of the three pairs of coils wound around the six-pole stator sets the motor into rotation. The four-pole rotor is equipped with an obturator and a centripetal device consisting of four spring-equipped shutters. By sliding out at four different speeds of the motor and blocking the light beam from the photodiodes the shutters disconnect the battery from the stator, thus effectively controlling the speed of the motor.

The trace spacing on the records of the ESS-5 can be adjusted to be 0.2, 0.3, or 0.6 mm and recording speed can be set at either 18 or 36 mm/min. A viewer enlarges the image by a factor of 16.6 increasing the trace spacing to 3.3, 5.0, or 10 mm and the recording speed to 300 or 600 mm/min. The reduced length of each of the three pendulums can be adjusted to be 5.8, 17.4, 58, or 174 cm, with magnification of the viewer becoming 30, 10, 3, or 1, respectively. The thickness of the trace on the film does not exceed 0.1 mm. The natural period of each pendulum can be varied between 1 and 3 sec. The damping of each seismometer is adjustable between 0.3 and critical. In the older system (ESS)

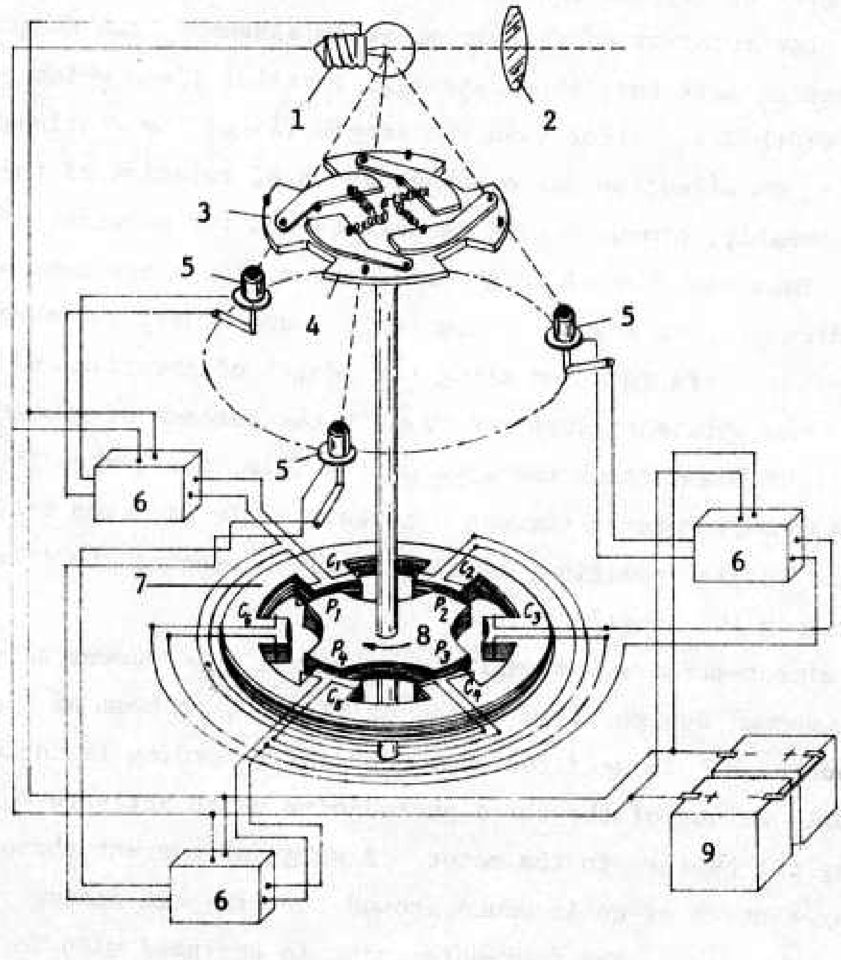

Fig. 34 -- Schematic drawing of the dc motor subassembly used in the ESS-5 seismograph system [49]

1 - incandescent bulb
2 - lens of the optical microrecording device
3 - four-blade obturator
4 - centripetal device consisting of four spring-equipped shutters for control of the motor speed
5 - photodiode
6 - electrical switch
7 - six-pole stator with three pairs of coils
8 - four-blade rotor
9 - battery

the magnification could be selected to be 2, 1.0, 0.5, 0.2, and 0.1. The ESS-5 system is hermetically sealed and is connected by a cable to a power supply (dry cell batteries). The system can operate at a temperature between -10°C and +40°C. The dimensions of the ESS-5 system are 42 x 44 x 44 cm and it weighs 35 kg. The frequency response of the older system (ESS-1) is shown in Fig. 29.

Q. AGS FREQUENCY-MODULATED CAPACITANCE ACCELEROMETER [52]

The sensing element of the AGS capacitance blast accelerometer, which is intended primarily for borehole use, is a flat duraluminum diaphragm that serves as the center plate of a dual capacitor. Each capacitor plate is connected to an RF oscillator. The diaphragm (center plate) responds by bending to acceleration of the frame perpendicular to its plane. Bending of the center plate reduces the capacitance of one of the outer plates and increases the frequency of the oscillator while increasing the capacitance and decreasing the frequency of the other outer plate and the oscillator, respectively. The diameter of the center plate is 5 cm and of the outer plates 3.2 cm. The two signals are mixed and the difference frequency is isolated by a low-pass filter. The first experimental series of the FM capacitance accelerometers were capable of measuring accelerations of up to 6, 12, 61, 122, and 610 g's. The electrical circuitry of the accelerometers is transistorized and, along with the dual capacitor, is enclosed within a steel housing. Except for the space between the capacitor plates, the inside of the accelerometer is filled with an epoxy compound. Power is supplied by 9-V batteries switched on by means of remote controlled relays. The initial difference frequency is 8 kHz. The open-circuit output voltage is about one volt. Nominal acceleration produces a frequency change of ±2 kHz. The voltage sensitivity of the AGS at the output of the low-pass filter is 0.5 to 5 V/kHz and current sensitivity at the input to the recorder is 20 to 75 mA/kHz. The sensitivity of the AGS accelerometer can be adjusted by changing the thickness of the center plate, the gap width, and the initial oscillator frequencies. Among the advantages of the FM capacitance accelerometer are high noise immunity and direct magnetic recording.

R. VIB SEISMOMETERS

The VIB series of electromagnetic seismometers without a damping device includes at least the following five models: VIB-A, VIB-U, VIB-CB, VIB-CG, and VIB-TKS. These seismometers coupled with light-beam oscillographs are used primarily as vibration-and-blast seismographs [53,54].

The VIB-A is intended for registration of either the vertical or horizontal components of particle velocity of the ground in the frequency range f $\geq$ 5 Hz with the peak-to-peak displacement amplitudes not exceeding 2 cm. The range of recorded velocities varies between 0.1 cm/sec and 10 m/sec. The technical specifications of the VIB-A are given in Table 6. The VIB-U seismometer is similar to the VIB-A, but records particle velocities of up to 5 cm/sec [53].

The only data available on the VIB-CB, VIB-CG, and VIB-TKS are the technical specifications listed in Table 6 [53].

Table 6 [53]

TECHNICAL SPECIFICATIONS OF VIB SEISMOMETERS

Seismometer	VIB-A	VIB-U	VIB-CB	VIB-CG	VIB-TKS
Natural period (sec)	0.6-1.1	0.6-1.1	0.65-5	0.65-5	0.65-5
Reduced length (cm)	10-120	10-120	13-624	13-624	13-624
Generator constant (G) V/(m/sec)	0.8	0.8	0.12	0.12	0.12
Dimensions (cm)					
l x w x h	17x18x16	14.5x16x22.5	--	--	--
d x h	--	--	10.7x26.5	10.7x26.5	10.7x84
Weight (kg)	4	5	8	8	25

S A-1 AND A-2 HORIZONTAL-COMPONENT ACCELEROMETER [55]

The A-2 electromagnetic accelerometer, developed for registration of the horizontal components of motion of up to 3 g in the frequency range 3 to 10 Hz, is a later model of the A-1 (see Fig. 35), which was designed in the 1950s. The A-1 and A-2 are equipped with two permanent magnets and two sets of signal and damping coils. The natural period of the A-1 is adjustable between 0.05 and 0.3 sec and its damping factor is 0.6 to 0.8. The maximum deflection of each of the two pendulums is 0.4 for the A-1 and 7 cm for the A-2. A light-beam oscillograph recording at a speed of 8 cm/sec is widely used with these accelerometers.

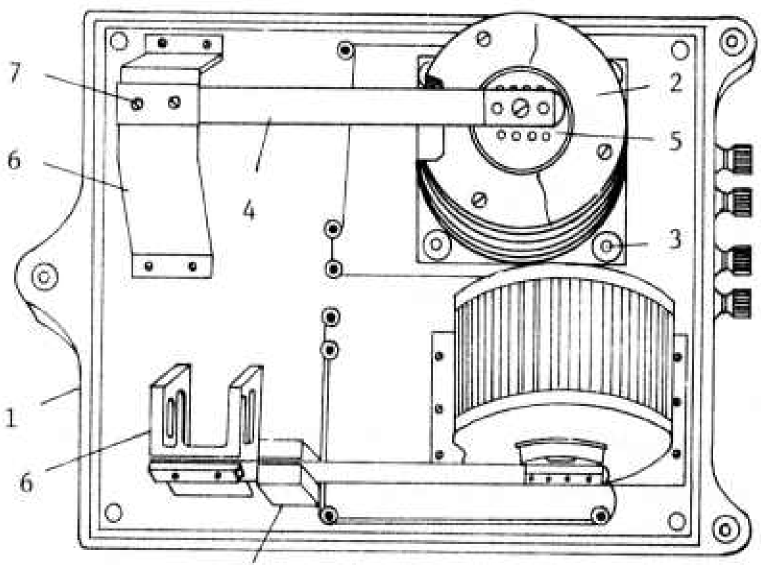

Fig. 35 -- Schematic drawing of the A-1 accelerometer [55]
1 - frame
2 - permanent magnet
3 - bolt
4 - pendulum
5 - coil
6 - stand
7 - bolt
8 - weight for adjustment of the seismometer period

Figure 36 shows the magnification curve of an accelerograph consisting of an A-1 accelerometer and an unspecified photographic recorder.

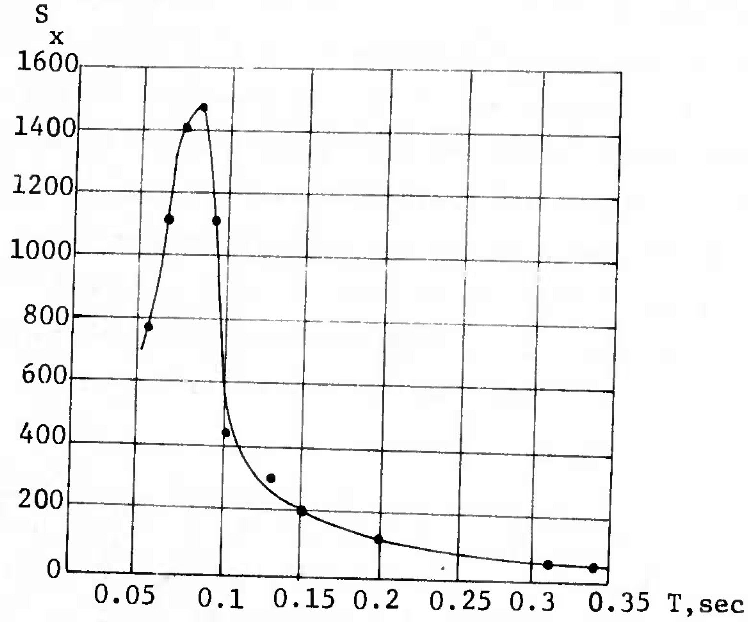

Fig. 36 -- Magnification curve of an accelerograph consisting of an A-1 accelerometer and an unspecified photographic recorder [55]

T. SPM-16 SEISMOMETERS [56,57,58]

A vertical-component accelerograph (SPM-16) consisting of a standard SPM-16 geophone coupled with a GB-III-3 galvanometer in the POB-12 light-beam oscillograph has in the past found some application in seismology, in recording seismic events of intensity I = IV to VI, and in seismic engineering. Another model of this vertical-component accelerograph (SPM-16M-A), consisting of a SPM-16 geophone -- modified to increase its natural frequency from 34 Hz to 50 Hz and the maximum recordable accelerations from 1.5 g to 4 g -- and a POB-12 oscillograph, was used to record accelerations induced by large chemical explosions. A displacement meter (SPM-16M-D) consisting of a SPM-16 geophone -- modified to decrease its natural frequency from 34 Hz to 10 Hz -- coupled with the heavily overdamped 20-Hz galvanometers used in the OT-24-51 seismic exploration recorder has found some limited application in measuring oscillations of man-made structures. The technical specifications of these two vertical-motion accelerographs and the displacement meter described above are given in Table 7.

Table 7 [56,57,58]

TECHNICAL SPECIFICATIONS OF PHOTOGRAPHICALLY RECORDING SYSTEMS INCORPORATING SPM-16 SEISMOMETERS

	SPM-16 (accelerograph)	SPM-16M-A (accelerograph)	SPM-16M-D (displacement meter)
f_s (Hz)	34	50	10
f_g (Hz)	5	5	20
D_s	0.35	--	0.6
D_g	20-25	20-25	15
G [V/(m/sec)]	65	65	65
Signal-coil resistance (ohms)	360	--	360
Acceleration sensitivity or maximum gain	7.8 (cm/g)	10, 1, 0.1 (cm/g)	1000
Shunt resistance (ohms)	200	700, 70, 7	--
Frequency range (Hz)	≤ 30	≤ 45	12-200
Maximum recordable acceleration (g)	1.5	4	--

U. FLUID ACCELEROMETER [59]

A schematic drawing of an unnamed fluid accelerometer, which consists of a cylindrical steel shell closed at both ends with membranes and filled with mercury, is shown in Fig. 37. As a result of motion of the accelerometer frame, which is rigidly attached to an oscillating object, mercury exerts pressure on both membranes causing them to flex. Bending of the membranes proportional to acceleration is sensed by strain gauges and is usually recorded by a light-beam oscillograph equipped with high-frequency galvanometers. The sensitivity of the accelerometer is determined by the mass of the fluid and the diameter and thickness of the membranes. The natural frequency of the accelerometer is 250 Hz. The response of an accelerograph consisting of a mercury accelerometer and a light-beam

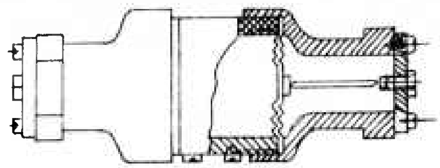

Fig. 37 -- Schematic drawing of the fluid accelerometer [60]

oscillograph is flat in the frequency range 5 to 80 Hz. The sensitivity of this system is 4.7 cm/g. The mercury accelerometer is well suited to be used with electronic amplifiers and other types of recording units.

V. K-001 VIBRATION SEISMOMETER PACKAGE [61]

The K-001 three-component vibration seismometer package developed in the late 1950s is intended for registration of displacements with amplitudes up to ±1 mm in the frequency range 2 to 200 Hz. It consists of three modified VEGIK seismometers, described in Section IV-C of this Report; a gain control unit; and six overdamped M-002 galvanometers (f_g = 25 Hz) with liquid damping, packaged as a single unit. A system consisting of a K-001 seismometer package and an N-700 light-beam oscillograph can be operated at gains of 30, 80, 200, and 500. Shake-table-determined and theoretically calculated magnification curves of such a system are shown in Fig. 38.

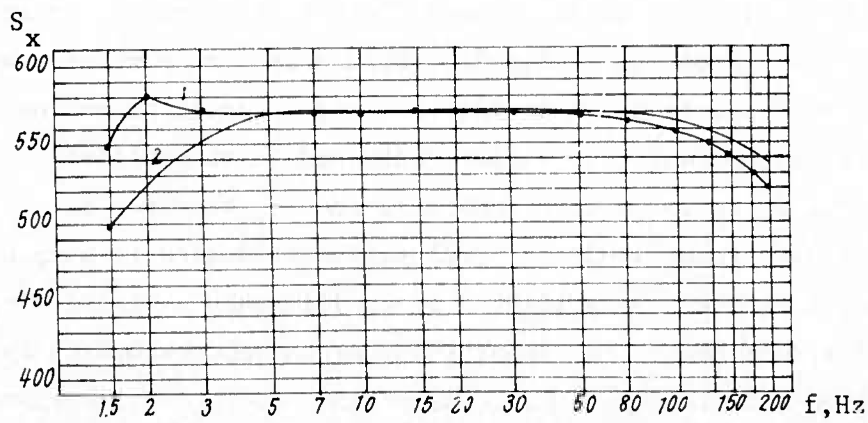

Fig. 38 -- Magnification curves of a vibration seismograph system consisting of a K-001 seismometer package and an N-700 light-beam oscillograph, determined from shake-table measurements (1) and theoretical calculations (2) [61]

W. VDTs-2 VIBRATION SEISMOMETER [62]

The VDTs-2 electromagnetic, moving-coil vibration seismometer is intended for registration of either vertical or horizontal components of displacement with amplitudes up to 1000 μm. The VDTs-2 is equipped with a vertical screw for balancing the pendulum and a horizontal one for adjusting its natural period. The seismometer is damped by means of external resistance. The response of a system consisting of a VDTs seismometer and an OT-24-51 seismic exploration recorder is flat between 1 and 50 Hz. The technical specifications of the system are as follows:

Seismometer	
Natural period	1.2 sec
Inertial mass	150 gm
Coil resistance	200 ohms
Galvanometer	
Natural frequency	20 Hz
Coil resistance	36 ohms
External critical damping resistance	1000 ohms
Minimum gain	350
Dimensions	15 x 11 x 16 cm
Weight	3 kg

In the late 1950s the seismometer was equipped with a remote pendulum position monitor and remote centering device and redesignated the VDTs-2N seismometer.

V. AUXILIARY EQUIPMENT

A. AUZ-IIM SEISMIC TRIGGER AND AUTOMATIC SPOT-BRIGHTNESS CONTROL [63,42]

The AUZ-IIM device has two stages -- an automatic spot-brightness control for photographic recorders, first stage, and a seismic trigger of the low-gain channel, formed by connecting a GB galvanometer to the damping coil of an SK or SKD seismometer, the second stage. The use of a shunt box in the low-gain channel makes it possible to reduce the gain of the standard broad-band SK or SKD seismographs, used at most of the Soviet permanent seismograph stations, from 1000 to as low as 50 without affecting the damping of the galvanometer or seismometer. The AUZ-IIM has an auxiliary light source which sends its beam on the same galvanometer mirror as the recording light. The beam reflected by the mirror falls on a screen between two photocells. When the amplitude of the seismic signal reaches a certain threshold, the light beam reflected from the moving galvanometer falls on one of the photocells. The current pulse, amplified by a two-stage transistor amplifier, switches on several relays; these increase the voltage on the lamps and their brightness for the duration of the earthquake, actuate the low-gain channel by turning on its light source, and set off a sound and flashing light alarm signaling device. The trace from the low-gain channel is superposed upon the record of the normal gain channel. The superposition of the two traces can be eliminated by means of a separate PZZ low-gain, three-channel, light-beam oscillograph actuated by the AUZ-IIM, which switches on the motor of the photographic paper transport mechanism and the light sources. The low-gain channel, operating at the optimum gain (50 times less than that of the SKD) records for a period of 30 minutes, or multiples of 30 minutes, and is automatically reset for standby operation.

B. FEPU SEISMIC TRIGGER [6,64]

The FEPU seismic trigger is a low-frequency, motion-sensitive switch designed to actuate POB-12M or N-700 light-beam oscillographs operating in standby mode. When the seismic signal exceeds a certain threshold, the light beam from one of the galvanometers falls on a photocell.

The signal is amplified by a transistorized, two-stage amplifier, which activates a relay closing the switch connecting the power supply to the oscillograph. The loss of motion is 0.5 sec and the oscillograph remains actuated for an adjustable period of time selected in accordance with the recording speed of the oscillograph. The dimensions of the FEPU seismic trigger are 30 x 20 x 15 cm and it weighs 2.5 kg. The current drain from a 6-V dc battery is 0.35 A. It is intended for operation at temperatures between -5°C and +40°C.

C. PU-1 SEISMIC TRIGGER [65]

The recently developed PU-1 seismic trigger, intended for operation with POB-12M, N-700, and other light-beam oscillographs operating in a standby mode, is a slightly modified model of the seismic trigger incorporated in the ISO-2M oscillograph. The PU-1 is connected to the signal or damping coil of one of the seismometers used with the light-beam oscillographs. The signal from the coil is fed into a transistorized, push-pull, three-stage amplifier, which controls the relays that actuate the light-beam oscillographs. The trigger, which can be used with either a vertical or a horizontal seismometer, can actuate three recording units and an alarm signaling device, or four recorders. The technical specifications of the PU-1 trigger are as follows:

Actuating characteristics	
Actuating displacement	0.5 to 1 mm
Actuating voltage	50 mV at 1 Hz
Signal passband	0.6 to 7 Hz
Input resistance	3 kohms
Closure timing	Adjustable between 10 and 30 sec
Current drain (standby mode)	4 mA from 4 batteries and 10 mA from a 24 V external source
Dimensions	20 x 17 x 12 cm
Weight	2 kg
Temperature range	0°C to 40°C

D. THE A-002 ATTACHMENT TO THE N-700 LIGHT-BEAM OSCILLOGRAPH [66]

The A-002 attachment to the N-700 oscillograph (see Fig. 39) provides visual registration of seismic waves generated by strong earthquakes. The A-002 is attached to the N-700 light-beam oscillograph instead of the standard, externally mounted film or drum cassette. The attachment consists of a loop of paper (1), the outer surface of which is covered with a layer of phosphor, in close contact with the drum (2). Light beams from the galvanometers of the N-700 oscillograph activate the phosphor which retains the image of the traces for a specific length of time,

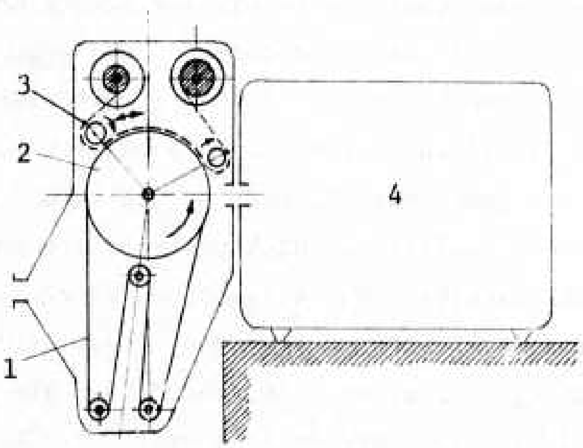

Fig. 39 -- Schematic drawing of the A-002 attachment to the N-700 light-beam oscillograph [66]
1 - loop of paper activated with a surface layer of phosphor
2 - drum
3 - photographic film
4 - N-700 oscillograph

less than that required for one full revolution of the drum. A photorelay is activated when the amplitude of a seismic signal exceeds a certain threshold; the photorelay activates both the motor that drives the film (3) and an electromagnet that brings the film in contact with the loop, thereby transferring the light-beam image to the film. Depending on the speed of the loop, its memory varies between 4 and 60 sec. The loop of paper is 11 cm wide and 1.2 m long; its speed can be adjusted

from 30 to 480 cm/min. The time period during which the loop is in contact with the film is also adjustable. Time marks from a clock are recorded by one of the galvanometers of the N-700 oscillograph. The dimensions of the A-002 are 30 x 26 x 52 cm and it weighs 17.6 kg. The attachment records ground motion with double amplitude of 5 mm up to frequencies of 5 Hz and 10 mm up to frequencies of 2.5 Hz. In the earlier model the thickness of the trace was 1 mm.

Appendix A

THE MSK-64 INTENSITY SCALE [59]

The MSK-64 scale, now used universally by Soviet scientists, measures earthquake intensity in units from 1 to 12. This is essentially the same as the Modified Mercalli scale now widely used in the United States. This Report uses MSK-64 units converted to Roman numerals. Table A-1 defines intensities 5 through 10 of the MSK-64 scale in terms of ground acceleration, velocity, and other parameters.

Table A-1 [59]

MSK-64 INTENSITY SCALE IN TERMS OF OTHER PARAMETERS

MSK-64 Intensity Units	(a) $\ddot{s}$ (cm/sec^2)	(b) $\dot{s}$ (cm/sec)	(c) s_o (mm)	(d) E x 10^{-5} (erg/cm^2-sec)
5 (V)	12-25	1-2	0.5-1	1.1-5.5
6 (VI)	25-50	2.1-4	1.1-2	5.5-27
7 (VII)	50-100	4.1-8	2.1-4	27-134
8 (VIII)	100-200	8.1-16	4.1-8	135-670
9 (IX)	200-400	16.1-32	8.1-16	670-3350
10 (X)	400-800	32.1-64	16.1-32	3350-16750

(a) -- $\ddot{s}$ is the maximum ground acceleration in the period range between 0.1 and 0.5 sec.

(b) -- $\dot{s}$ is the maximum velocity in the range between 0.5 and 2 sec.

(c) -- s_o is the maximum displacement amplitude of the center of mass of the pendulum of the SBM seismoscope with a natural period of 0.25 sec, logarithmic decrement of 0.5, and damping factor of 0.08. The ground motion is recorded at a magnification of 1.1 relative to the center of oscillation.

(d) -- E is the energy flux.

Appendix B

SEISMIC ENGINEERING NETWORKS

In early 1967 Soviet seismologists began to deploy sets of strong-motion instruments inside and in the vicinity of buildings, dams, and other man-made structures.* According to [4], by May 1973 sixty of these "seismic engineering stations" had been set up in more than fifteen cities and at four of the largest dams.

The site selection for the sets of instruments is based on the following criteria:

(a) typical buildings in a city constructed on different types of ground
(b) different types of buildings constructed on the same type of ground
(c) high-rise buildings
(d) large industrial buildings

In buildings of over nine stories the instruments are installed in the basement, midway up the structure, at 0.8 of its height, and on the roof. The strong-motion seismographs deployed include the VBP-3 and S5S seismometers and SPM-16 and OSP accelerometers coupled with light-beam oscillographs. Other standard instruments at the stations are the three-component, optically recording UAR or SSRZ accelerographs, and SBM and IGIS(AIS) seismoscopes. The VBP-3, S5S, SPM-16, and OSP with light-beam oscillographs are also installed in steel or concrete vaults constructed below ground level at a distance from the building of two to three times its height.

The minimum required set of instruments at each location for a seismic engineering station in buildings of over nine stories consists of a three-component SSRZ accelerograph, one vertical and two horizontal

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*Information on these stations appeared in Z. I. Aranovich, D. P. Kirnos, and V. M. Fremd, *Apparatura i metodika seysmometricheskikh nablyndeniy v SSSR* (Instruments and Observation Methods Used at USSR Seismographic Station), 1974, which was received too late for inclusion in the body of this Report.

VBP-3 seismometers coupled with an N-700 light-beam oscillograph, and a common power supply installed in the basement, on the roof, and in the vault near the building. The output of each VBP-3 seismometer and of the vertical-component transducer in the SSRZ is recorded at two different gain levels. Each system, consisting of a VBP-3 seismometer and an N-700 recorder, is triggered by the same vertical-component S5S seismometer (apparently installed in the basement). The speed of all recording units is 20 mm/sec. The MKh-6 chronometer is the timing system used with all recorders. One AIS and one SBM seismometer are also installed in the basement of the building. The high-gain vertical component can record earthquakes of intensity between III and VI, and the normal-gain, three-component channels of the SSRZ can record ones between VII and X. The systems consisting of VBP-3 seismometers and N-700 recorders operating at two gain levels can record earthquakes of intensity between V and IX.

A set of strong-motion instruments recommended by the Institute of Physics of the Earth for deployment in buildings over nine stories high, and a set that exceeds considerably the minimum required, is shown in Fig. B-1.

A standard set of instruments may be deployed at as many as twenty sites on the surface of the dam, inside the structure itself, and at various points in the canyon in close proximity to the dam. A standard set of instruments consists of an SSRZ or a UAR accelerograph and the following three-component systems with galvanometric registration: two S5S, one VBP-3, and one SPM-16. All systems operate in a standby mode.

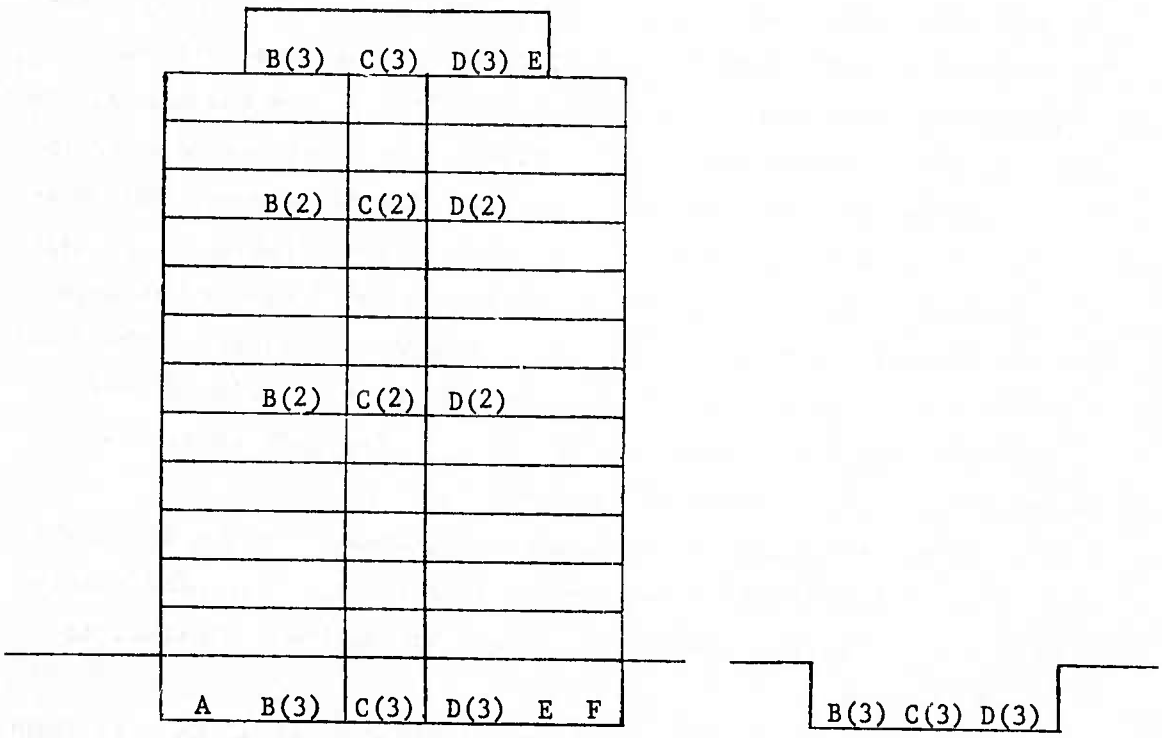

Fig. B-1 -- Distribution of strong-motion instruments and seismoscopes in a tall building (Numbers in parentheses indicate the number of components per instrument)

A - AIS or IGIS seismoscope
B - SPM-16 or OSP
C - VBP-3
D - S5S
E - 3-component UAR or SSRZ system
F - SBM seismoscope

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